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General Technical
Report PSW-36

Measuring Moisture Content in Living Chaparral:

a field user's manual

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CHAPARRAL
RESEARCH AND DEVELOPMENT PROGRAM

The Authors

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PREFACE

In 1977, the Forest Service, U.S. Department of Agriculture established a research and development program at this Station titled "Vegetation Management Alternatives for Chaparral and Related Ecosystems." This 5-year program, headquartered at Riverside, California, is an intensive effort to develop, test, and demonstrate a wide range of options for maintaining or increasing the productivity of chaparral and related ecosystems in southern California.

This manual is based on a report by the Physical Dynamics Corporation, Bellevue, Washington, as part of its contract with the program. It is intended for field use. Supplementing the manual are two short slide-tape training programs that describe the procedures for collecting and drying chaparral samples.

Comments about the manual should be directed to:
Program Manager
Chaparral Research and Development Program
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Copies of the slide-tape training program may be ordered from:
National Audio-Visual Center
General Services Administration
Washington, D.C. 20409
Request: Fuel Moisture Sampling—A01013-5500 (contains two programs); price: $36 U.S. Make check, money order, or purchase order payable to *National Archives Trust Fund.*

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This manual standardizes procedures for determining the moisture content of living chaparral for use in a proposed statewide system of monitoring living fuel moisture. The manual includes a comprehensive examination of fuel moisture variations in California chaparral, and describes techniques for sampling these variations. Equipment needed to sample and determine living fuel moisture is discussed. Detailed procedures for collecting living fuel samples and processing the samples for moisture content are provided.

Retrieval Terms: fire management; chaparral; prescribed burning; fuel moisture; living wildland fuels; chamise; manzanita.

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The strong influence that variations in the moisture content of living material in chaparral has on fire behavior has long been recognized by wildland fire managers and fire scientists. However, uniform and valid techniques for measuring living chaparral moisture and incorporating this fuel parameter into the various aspects of fire management have not been generally available for field use.

This manual describes the factors affecting living chaparral moisture, the requirements for establishment of fuel moisture sampling areas, and the procedures for collecting fuel samples and determining their moisture content using conventional laboratory drying ovens.

The basis of living fuel moisture determination has been a recurring problem, frequently appearing in the form of a question as to how the fuel can have more than 100 percent moisture. Moisture content of many substances is given as the proportion of water in the substance, and therefore must always be less than 100 percent. However, it is more appropriate to express the moisture content of wildland fuel in relation to dry weight, since it is the dry material that provides the heat to evaporate the water so that the fuel will burn. Also, fuel loading is expressed in terms of dry weight; if wet weight were used, adjustments in the energy potential would have to be made for moisture content. Consequently, expressing moisture content as percent of dry weight is consistent with the method of measuring fuel loading.

Although living fuel moisture is a major influence on fire in chaparral, it is only one of several fuel and environmental parameters affecting fire behavior. Consequently, living fuel moisture alone cannot be used to evaluate adequately potential fire hazard and fire behavior. Used in conjunction with the effects of other fire behavior influences, however, knowledge of the level and trends of living fuel moisture can greatly improve the accuracy of appraisals of fire hazard and the prediction of fire

behavior for use in fire control, fire prevention, and prescribed fire activities.

Typically, 55 to 75 percent of the total standing fuel in mature chaparral is living material. The amount of moisture in this living material is almost always much greater than that in the dead material during the fire season. Because of its high moisture content, living fuel will seldom burn by itself in its natural arrangement. Heat from burning dead fuel is needed to dry the living material sufficiently to allow it to burn and add to the heat output of the fire. Since a relatively small amount of dead fuel is usually uniformly distributed through the chaparral shrub crowns, it does not burn well by itself under normal conditions; the distance between dead fuel elements is too great for intense combustion. For a hot fire to develop in chaparral, then, a large part of the living material must also burn along with the dead fuel. But the combustibility of living fuel is strongly influenced by its moisture content, and this varies greatly with time and place. Consequently, the moisture in living fuel is a major determinant of chaparral fire behavior. It may sometimes determine if the chaparral will burn at all.

MOISTURE VARIATION IN LIVING FUEL

The moisture content of living chaparral in California follows a distinctive annual pattern *(fig. 1)*. When spring growth starts, the moisture content of the new plant material rises rapidly to a peak, often to more than 200 percent of its dry weight — for some species, to greater than 300 percent. The moisture in older foliage and twigs also increases during this period, although to a lesser degree than for new growth. In larger shrub stems and trunks, the increase in moisture is relatively small. Consequently, most of the change in moisture that affects fire behavior is in the foliage and small material. As the long, nearly rainless season progressively sets in, the moisture content of the shrubs decreases, reaching a minimum when the shrubs become dormant in the fall. The moisture then remains at a relatively low level until growth resumes in the spring.

Although the moisture content of living chaparral usually follows the same general annual pattern, significant variations occur between years and from place to place. Changes in moisture content are related to the physiological activity of the shrubs, and this activity is greatly influenced by soil moisture and the temperature of the soil and the air. When precipitation is deficient in winter and early spring, less new growth is

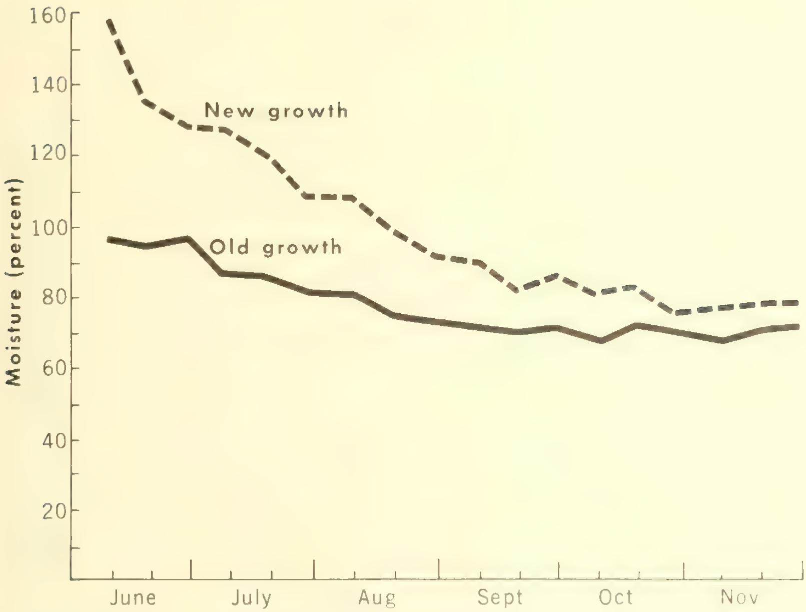

Figure 1—Twelve-year average seasonal variation in chamise moisture content in the Angeles National Forest.

produced and peak moisture in the living material is less than in other seasons when soil moisture is more plentiful. If soil moisture deficiency persists through the summer, shrub moisture drops more rapidly and may reach a lower point in the fall than when soil moisture is normal.

Soil and air temperatures affect the time new growth starts and the level of moisture attained by the shrubs. The new growth will start earlier and often reach a higher level of moisture when the weather in late winter and spring is warm than when the weather is cold. Other factors that affect soil and air temperatures, such as slope aspect, slope, steepness, and site elevation, also affect the amount of new growth, the time it starts, and the level of moisture in the living material.

The moisture patterns of different chaparral species vary somewhat, particularly in the peak moisture reached in the growing season and in the moisture content at dormancy. Moisture variations are also found between shrubs of the same species in the same locale, and often in material taken from different heights and aspects on the same shrub. Site quality also affects shrub moisture: shrubs on good sites tend to produce more new growth, have higher moisture levels, and decrease in moisture content more slowly during the summer than shrubs on poor sites. Dry foehn winds, such as the Santa Ana winds of southern California, and the Mono winds in the northern part of the State can

significantly reduce shrub moisture levels in a few hours. This lower moisture may persist for several days after the winds cease, particularly when soil moisture is deficient.

Visual indicators of the amount of moisture in living chaparral are few, the amount of new growth being about the only perceptible one. Analog devices are not yet available for estimating living fuel moisture, such as the fuel moisture indicator sticks used for dead fuels, nor have adequate predictive models for living fuel moisture been developed. Consequently, the direct measurement of fuel moisture by periodic sampling of living fuel and laboratory methods of fuel moisture determination are necessary to obtain estimates of the moisture content of living chaparral.

SAMPLING FUEL MOISTURE

The principles applied in sampling and monitoring living fuel moisture are akin to those used in the observation and monitoring of fire weather. Fire weather observations are made at a station selected as being typical in weather characteristics of the geographical area of interest. Because of geographical variability of local weather, however, observations at the station at any given time are not likely to correspond precisely to weather conditions at other points within the area. Therefore, a weather observation at the station is actually only a sample of the weather for the larger geographical area, and this sample may only approximate weather conditions over the area as a whole.

Observation of living fuel moisture requires an area of a few acres that is deemed representative of a more extensive geographical area for those conditions affecting living fuel moisture. Samples of the living material are then collected from this small area for moisture determination. Thus, this fuel moisture sampling area serves the same function in fuel moisture monitoring as does the weather station in the monitoring of fire weather. Like the fire weather sample, the fuel moisture sample may only approximate the living fuel moisture conditions over the larger geographical area because of the spatial variations in influences affecting living fuel moisture.

Comparability of fire weather observations between stations is effected by standardization of weather instruments, the exposure of these instruments to weather conditions, observation procedures, and the specific time that observations are made. Comparability of living fuel moisture observations is achieved by standardization of fuel sample collection and moisture determination procedures, limitation of individual samples to one species, and by specification of sampling conditions.

Selecting Sampling Areas

The moisture in living chaparral is controlled chiefly by the local climate and the physiological response of the shrubs to that climate, as determined by the characteristics of separate species and individual plants within that species. Consequently, both the climatic variations and the response of the shrubs to those variations must be considered when sampling living chaparral for moisture content.

Establishing a system for the observation and monitoring of living fuel moisture first requires the selection of areas for which moisture information is required. Climatic variation is the primary parameter to consider in setting the boundaries of these areas. Differences in moisture between species can be accounted for in the selection of species to be sampled. Variations in sample moisture resulting from differences in shrub characteristics can be minimized by proper sample collection procedures.

Local climates in California are influenced by numerous factors, including elevation, latitude, slope steepness and aspect, precipitation patterns, and location of the area with respect to synoptic weather pattern tracks and proximity to the ocean. Outlining the boundaries of local climatic zones ideally is accomplished through a detailed climatic analysis of the State. However, this would be a major endeavor that could not be done immediately. Until such an analysis could be made, delineation of climatic zones must be based on general knowledge of local climatic variations. The fire danger rating areas used in the California Wildland Fire Danger Rating System were based on a partial climatic analysis; therefore, these areas can provide a guide to delineate climatic zones for fuel moisture sampling.

At least one fuel sampling area must be established for each climatic zone. These areas should be chosen as best representative of the general characteristics of the zone regarding elevation, slope aspect and steepness, site quality, and chaparral species; or representative of the same influences in that portion of the zone where the primary fire problems exist.

Key Sampling Areas

The primary purpose of fuel sampling areas in climatic zones is twofold: to provide living fuel moisture information for local use in fire control and prevention and to improve fire danger ratings. Living fuel moisture information, however, has effective broader statewide applica-

tions—comparison of fire hazards between different parts of the State as a guide to special fire prevention actions, such as area closures; the reallocation of firefighting resources to those areas of greatest hazard at different times during the fire season; and statewide monitoring of living fuel moisture as a guide in establishing opening dates of the fire season in different areas.

These broad uses of living fuel moisture information require that comparisons be possible between different parts of the State, defining fuel moisture levels and trends as affected by changes in weather patterns from year to year and within a fire season. A special system of key sampling areas is needed to meet this requirement. As in local climatic areas, statewide comparison of climatic variation is the primary parameter to be considered in establishing key sampling areas. Climatic variation must only be evaluated on a broader scale. Each *major* climatic pattern in the State should be represented by a key sampling area. California's climate varies from west to east and from north to south, and is also strongly influenced by the State's mountain ranges. As a minimum, separate key sampling areas should be established for coastal areas, west and east slopes of the major inland valleys, and the east side of the Sierras in both northern and central California. In southern California, coastal areas and inland mountain slopes should each be represented by separate key sampling areas.

To preserve climate as the primary variable between key sampling areas, the topographic features of the areas should be similar and preferably representative of the more severe climatic conditions. Thus, the key sampling areas should be located on south-facing slopes and at lower elevations. Site quality should also be similar. Ideally, the same single chaparral species should be sampled in all key areas. In practice, this is not possible, since a single species does not predominate throughout the State. However, either chamise or upright growing manzanita usually abounds in most areas and the sampling should be limited to these species whenever possible. Where the ranges of the two species overlap, both chamise and manzanita can be sampled in a key area to provide a bridge for the evaluation of weather effects on living fuel moisture between key areas. If necessary, this same bridging technique can be used to add a third species for some key sampling areas.

Some of the sampling areas in the climatic zones may also meet the specifications for the key sampling areas; these may be used for both key area applications and local uses. For some of the broad climatic patterns, however, separate key sampling areas are likely to be necessary to meet the uniformity requirement of key sampling areas.

Year-to-year comparison of fuel moisture levels and trends is an important function of all sampling areas. Therefore, both the key sam-

pling areas and local climatic zones should be located on sites likely not to be disturbed over a period of years.

Fuel Moisture Sampling Period

Moisture sampling in the key areas should begin before new spring growth starts and continue until the end of the fire season. This permits monitoring of living fuel moisture from shrub dormancy to peak moisture, through the decline of moisture during the summer, and into the often critically low moisture period in the fall. For southern California, year-long moisture sampling in the key sampling areas may sometimes be necessary.

The time of year that sampling of local areas should begin is dictated by the use and need for moisture information. If the same kind of information as provided by the key areas is desired, the sampling should commence before new growth starts and continue to the end of the fire season, as with the key sampling areas. For areas at low elevations, the time to start sampling will be about the same as for the nearest key sampling area. Sampling at higher elevation areas can begin later. Over much of California, new growth is usually delayed 7 to 10 days for each 1000-foot increase in elevation. In climatic zones where prescribed burning programs are being conducted, year-long sampling is desirable to provide a guide to the optimum time for the burns.

For some applications of living fuel moisture data in the local climatic zones, season-long monitoring of fuel moisture may not be necessary. It is often of primary interest only to know when the living fuel moisture is approaching a critically low level, so that intensified fire prevention and other precautionary fire control actions can be initiated to offset the increased hazard. Since key areas are located where fuel moisture can be expected to first approach the critical level, moisture data from the nearest key area will indicate when to start sampling the local area.

Living fuel moisture usually changes slowly, therefore sampling periods about 10-14 days apart normally will be sufficient to indicate moisture trends; however, additional samples during prolonged heat waves or foehn wind periods may be desirable.

Number of Samples

The new and old growth should be sampled separately as long as they can be distinguished, owing to large differences in moisture content be-

tween new and old growth material during much of the year and the highly variable amount of new growth from year to year. At least three samples each of new and old growth for each species sampled in a given area should be collected for each sampling period. Multiple samples will provide a better estimate of the average moisture for the sampling area than will a single sample. As a data bank of fuel moisture information is collected, multiple sampling will permit statistical analysis of moisture variation within the sampling area and the limits of accuracy of the average moisture contents obtained.

Size of Sampling Areas

Each sampling area should contain an ample number of shrubs so that only a few twigs need to be removed from each shrub during a sampling period. Otherwise, repeated sampling of only a few shrubs can soon deplete the supply of sample material and may adversely affect shrub growth and, consequently, the accuracy of the moisture sample. In areas sampled over a large part of each year, 7 to 10 acres normally will contain enough shrubs. However, if the shrubs are small or sparse or more than one species is to be sampled, a larger area may be needed. Areas sampled for only a few months each year can be smaller — 3 to 5 acres will usually be adequate.

Documentation

The boundaries of both key and local sampling areas should be marked with durable wood or steel posts. Plot the location on a general area map and provide sufficiently detailed written information of location and access routes — highway number or name, distance from easily recognized landmarks, etc. — to permit the area to be readily found. A written description of the sampling area, giving elevation, slope aspect and steepness, size of the area, predominant species, and the age of the chaparral, is of major importance in making maximum use of the collected moisture data. Pictures of the area are also desirable. Each sampling area must be given an identifying name or number.

SAMPLING FOR PRESCRIBED BURNING

In prescribed burning, representative estimates of living fuel moisture must be obtained for the planned burn area, instead of for a climatic

zone as in the monitoring of general levels and trends of fuel moisture. Temporary line transects, rather than sampling areas, are best suited to sampling fuel moisture for prescribed burning. Differences in soil moisture, slope aspect, slope steepness, elevation, site quality, and chaparral species all can cause variations in living fuel moisture over the planned burn area. Consequently, the number of transects needed to adequately sample a planned burn area depends on the amount of variation in these parameters. For example, a burn area that is predominately on a slope of one aspect and steepness which contains mostly a single chaparral species can be adequately sampled with a single transect running from the bottom to the top of the slope, in an area generally representative of the burn area; but if major differences in aspect, slope, or species exist, additional transects are desirable. In general, the number of transects needed will increase with the size of the burn, primarily because variations in the parameters controlling living fuel moisture are more likely to be encountered as the burn size increases. If evaluation of probable fire behavior in different parts of the burn is desired, then transect sampling of major variations in the controlling parameters will be needed.

Transects to be sampled more than once should be marked so that fuel samples are collected from the same area each time. The transects should also be plotted on the burn area map to aid postburn evaluation of fire results and fire behavior. For prescribed burning, fuel sample collection procedures and the number of samples are the same as for permanent sampling areas.

Fuel moisture information from the permanent climatic zone and key areas can serve as a guide to start of sampling in the prescribed burn area. Burn area sampling should begin first along a transect that will define general fuel moisture conditions in that area. More detailed transect sampling can then begin as the fuel moisture level approaches that of the burning prescription. High detail sampling usually is not required until a few days before the burn date.

PROCEDURES

Of the several methods available for determining the moisture content of wildland fuels, drying the fuels in a conventional laboratory drying oven appears to be best for monitoring living chaparral moisture levels and trends. Determining moisture content by oven drying has long been a standard technique in science and industry, and equipment designed for the purpose is readily available. The method is very simple: freshly collected samples of foliage and twigs are weighed, dried in an

oven for a specified period at a temperature slightly above the boiling point of water, then weighed again. The moisture content of the fuel sample can then be calculated, based on the weight measurements obtained before and after oven drying. Since the drying process does not require monitoring, the cost in technician hours for the moisture determination process is low. Safety problems are few—the process is not any more hazardous than using a domestic oven for cooking food.

By using the equipment and techniques described herein, reliable moisture content estimates of chamise and manzanita (and of species with similar characteristics) can be obtained within a drying time of 15 hours. Thus, if fuel samples are collected during the day and placed in the oven by 1700 hours, the samples can be removed from the oven and their moisture content determined by 0800 on the next day.

EQUIPMENT

Drying Ovens

Two general types of electrical drying ovens are available—mechanical convection ovens and gravity convection ovens. Mechanical convection ovens use a fan or blower to circulate and to vent moist air from the oven. Gravity convection ovens depend on the natural upward movement of heated air for circulation and ventilation. Good quality ovens of both types have dual temperature controls. The secondary control is set a few degrees higher than the primary control; if the primary control fails, the secondary control will regulate the temperature and thereby prevent damage to the oven and its contents.

Mechanical convection ovens with dual temperature controls *(fig. 2)* are recommended where samples are processed on a regular basis. Gravity convection ovens cost 15 to 20 percent less, but the superior performance of the mechanical convention type makes the additional investment worthwhile. Because of forced circulation in a mechanical convection oven, vertical and horizontal temperature gradients are small and the drying of the fuel samples is more uniform than in a gravity convection oven. Temperature recovery after the samples are placed in the oven is much faster in a mechanical convection oven—20 to 30 minutes, compared with 4 to 10 hours in a gravity convection oven. Because of better circulation and more rapid temperature recovery in mechanical convection ovens, the drying time of fuel samples is 3 to 5 hours less than in the gravity convection type.

The required oven size will depend on the number of fuel samples to be processed at one time and the dimensions of the sample containers.

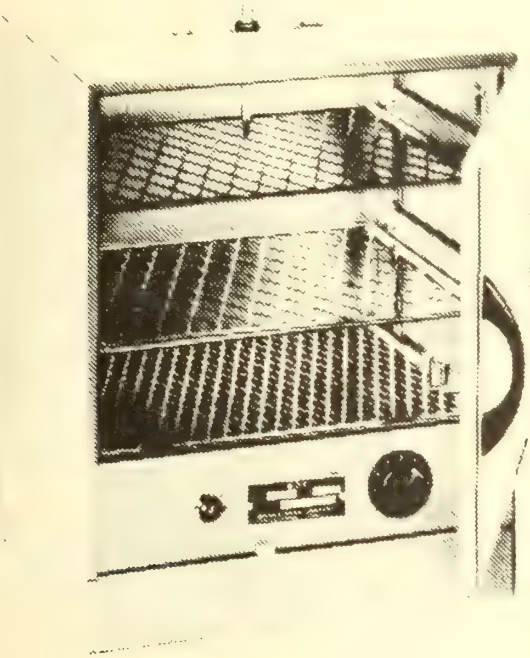

Figure 2—Laboratory drying oven.

At least 370 cubic inches of oven volume and approximately 40 square inches of shelf space must be allowed per sample to permit effective air circulation and moisture venting. Sample containers must be at least 3 inches from the bottom of the oven and not closer than 3 inches from the top. If more than one shelf is used in the oven, the tops and bottoms of the containers on the different shelves should be separated by 1½ to 2 inches. The smallest mechanical convection ovens generally available have a working volume of about 4500 cubic inches—sufficient volume for 12 fuel samples. However, because of the shelf area and vertical spacing requirements for the containers, the interior dimensions of an oven of this size may limit sample capacity to less than 12. In selecting a drying oven, then, attention must be paid to the dimensions of the sample containers and the oven interior as well as to oven volume.

Sample Containers

One-quart metal paint cans are recommended for the collection and drying of fuel samples. These containers are available through most paint stores or can be ordered in quantity from the manufacturer. The container can be reused several times if a paint can opener and reasonable care are used. Drying time is very sensitive to the compactness of the fuel sample, and the quart-sized containers permit collection

of the required amount of material without compressing the fuel in the container.

One-quart, wide-mouth glass canning jars have often been used for the collection and drying of fuel samples but have some disadvantages compared with metal containers. The weight of the jars is more than three times that of the metal containers and they are easily broken. The large mass of jars along with the low thermal conductivity of glass result in a relatively slow heating rate of the fuel samples in the drying oven. Consequently, fuel samples in jars must be dried about 3 hours longer than for the same amount of samples in metal containers. The jars are also about 3 inches taller than the metal containers. This increased height may affect the number of samples that can be dried at one time. For example, two shelves of metal containers can be dried in an oven with an interior height of 18 inches, but only one shelf can be utilized if glass jars are used.

Plastic containers are generally unsatisfactory for drying fuel samples. These containers tend to become soft under the required prolonged heating, and some types may shrink enough to prevent the cover from providing a tight seal on reuse. Some plastics may also release toxic vapors when heated.

Collecting samples in containers different than those in which they will be processed for moisture determination is not recommended. Because of the high moisture content of living fuel, moisture almost always condenses on the interior of the container and its cover. This moisture cannot be transferred from one container to another and accounting for it greatly complicates the moisture determination process. Any loss of fuel material during the transfer may also cause significant error in the moisture content.

Laboratory Balances

Either beam or torsion-type balances may be used to weigh fuel samples. The balance must have a capacity of at least 300 grams if metal containers are used and 600 grams for glass canning jars. The balance used must be direct reading to 0.1 gram; balances requiring the estimation of weight between 1-gram increments are not satisfactory. Top-loading balances *(fig. 3)* are easier to use and preferable to the hanging pan-type balance, since some kinds of hanging pan balances will not accommodate the sample containers.

Electronic balances are very easy to use, permit rapid weighing, and tend to reduce weighing errors. These balances are expensive, however, and their use in fuel moisture determination is probably not justified unless large numbers of fuel samples are weighed frequently.

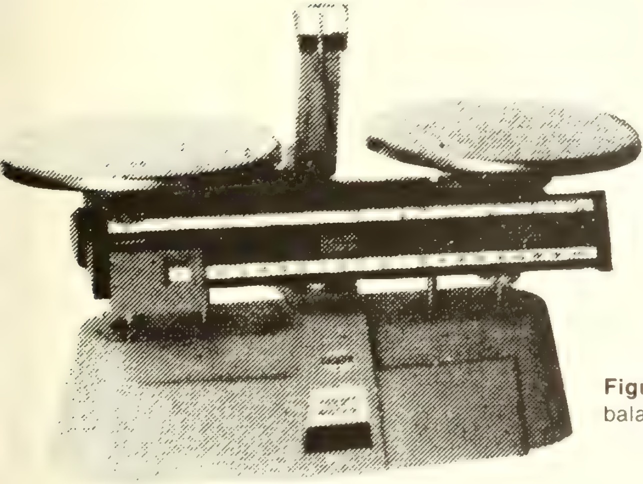

Figure 3—Laboratory balance.

COLLECTING LIVING FUEL SAMPLES

Uniform and systematic fuel sample collection procedures are essential for securing valid and useful living fuel moisture information. Haphazard collection of samples will produce erratic and inconsistent results leading to erroneous assessments of the fire hazard. Fuel samples for monitoring the levels and trends of living fuel moisture in California chaparral are to be taken from preselected and demarcated sampling areas. Normally, these areas will range in size from 3 to 10 acres. Only a single species of chaparral will be collected in most areas, but in some areas two species may be specified.

Preparing Sampling Area

It is important to ensure that the moisture content derived from fuel samples best represents the average moisture for the sampling area; the material must be collected from as many of the shrubs of the designated species as possible, and this material must be collected from the entire sampling area each time that samples are collected. Collection routes providing access to all parts of the sampling area must be established before collection begins. These routes may meander through the area or may follow more or less straight lines, whichever best suits the topography. Some pruning and slashing may be necessary in dense

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LIVING CHAPARRAL FUEL SAMPLE

AGENCY	ADMIN. UNIT	CLIMATIC ZONE	SAMPLE AREA
USFS	LOST RIVER R.D.	#10	HIGH MTN.

COLLECTION RECORD

BY	DATE	TIME
E.Z.	7/21/79	14:30

MOISTURE DETERMINATION RECORD

BY	TIME IN	DATE	OVEN LOCATION
I.R.	1700	7-21-79	LOW ROCK R.S.

OVEN TYPE (Circle One) M.C. G.C. — TIME OUT 0815 — DATE 7-22-79

NO.	CONDITION OLD	CONDITION NEW	SPECIES	CAN NUMBER		CHECK CAN NUMBER ACTUALLY WEIGHED	A GROSS WEIGHT WET	B GROSS WEIGHT DRY	C CAN WEIGHT	D DRY WEIGHT	E WEIGHT LOSS	F % MOISTURE
1	X		CHAM	4	→	4	207.8	165.3	134.6	30.7	42.5	138.4
2		X	"	12	→	12	211.7					
3	X		"	8	→	8	205.2					
4		X	"	6	→	6	202.0					
5	X		"	3	→	3	212.3					
6		X	"	10	→	10	217.9					
7					→							
8					→							

PHYSICAL OBSERVATION

NEW GROWTH:
- STARTING ☐
- CONTINUING ☒
- COMPLETE ☐
- NONE ☐

FLOWERING:
- STARTING ☐
- PEAKING ☐
- DECLINING ☐
- DRYING ☒
- NONE ☐

FRUIT:
- PRESENTING ☐
- FALLEN ☒
- RIPE ☐
- NONE ☐

WEATHER

DRY BULB 81 °   RELATIVE HUMIDITY 21 %

WET BULB 59 °   % CLOUD COVER 0 %

(B - C) = D; (A - B) = E; (E ÷ D) X 100 = F

REMARKS: 165.3-134.6=30.7

207.8-165.3=42.5

$\frac{42.5}{30.7} \times 100 = 138.4$

stands to provide access, but care must be taken to avoid unwarranted disturbance to shrubs of the designated species. Conspicuously mark the collection routes, such as with flagging, so that the same route can be followed each time the area is sampled. Fuel sample collection is facilitated if the collection routes are divided into three parts, each containing approximately one-third the total accessible shrubs of the designated species.

Equipment

The following equipment is needed to collect the fuel samples:

- Sample containers (1-qt. paint cans)
- Small pruning clippers
- Fuel sample collection record forms *(fig. 4)*
- Portable ice chest
- Paint can opener *(fig. 5)*
- Plywood disk
- Sling psychrometer *(fig. 6)*
- Map showing location and name or number of the sampling area

Figure 5—Paint can opener.

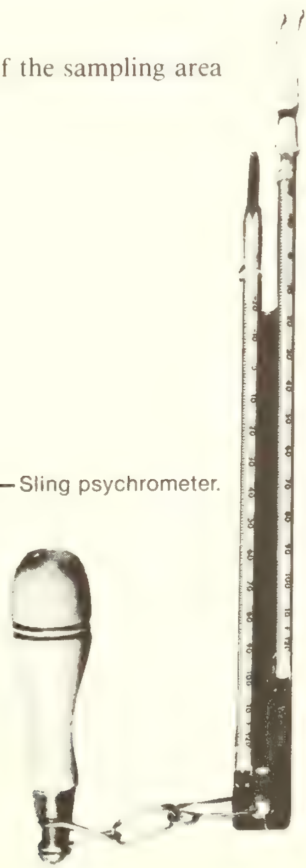

Figure 6—Sling psychrometer.

SAMPLE CONTAINER WEIGHT RECORD

Container Number	Weight	Type	Date Weighed
54	134.6 G	1-Qt. CAN	6/29/79

Figure 7—Sample container weight record.

Number each one-quart metal sample container and its lid. (Felt tipped marking pens with semipermanent ink work well for this.) Matching the containers and lids is easier if the containers are numbered on two sides. Each container *with its lid* must be weighed to the nearest 0.1 gram before use (see moisture determination section below for weighing procedures). The weight may be marked on the container, but a written record of the container numbers and weights also must be made *(fig. 7)*.

The portable ice chest is used to transport samples from the sampling area to the processing center. The chest should be large enough to hold the total samples collected on each trip. Styrofoam chests are adequate, but metal or hard plastic-covered types are more durable.

Use the paint can opener to open the sample containers. Other tools, such as screwdrivers and bottle openers, are likely to distort the container lid and prevent a tight seal.

Collecting Fuel Samples

Time of Day

Fuel samples should be collected during the normally hottest part of the day, usually between 1100 and 1500 hours in the spring and summer and between 1100 and 1400 hours in the fall. *Do not* collect samples when the chaparral foliage is wet from rain, dew, or fog; fuel moistures derived from samples collected under such conditions can be greatly in error. Wait for a more favorable day if necessary.

Material Collected

Collect only twigs with the foliage attached. *Maximum size of the twig must not exceed ⅛ inch diameter where it is cut from the shrub.* Smaller material usually can be collected. Cut off any flowers, seed pods, nuts, berries, and similar material *(fig. 8).* Also remove any dead material. Only the live twigs and foliage should be put into the sample container.

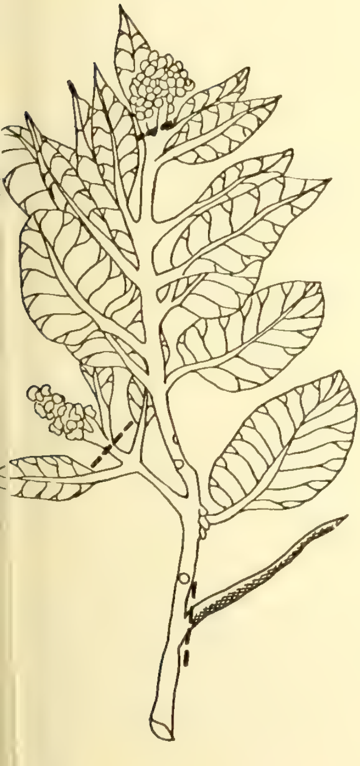

Figure 8 — Remove flowers, seed pods, nuts, berries, and any other unwanted living or dead material from sample live twigs and foliage.

Sample Size

The *dry weight* of the sample should be 25 to 35 grams. But since dry weight can be determined only after oven drying, the amount of material to be collected must be judged from the depth of the fuel in the sample container. A larger volume is needed when the moisture content is high. Also, the volume must usually be greater for species with rigid twigs that give a very loose pack in the container. New growth manzanita and chamise at the peak growing season require that sample containers be filled about three-quarters full to give the required dry weight. For old growth manzanita and chamise during the same period, filling the containers a little over one half usually provides the correct amount of dry material. As the season progresses and moisture in the chaparral decreases, the volume of material collected can also be decreased, particularly for new growth. Check the dry weight of the samples after they are processed and, if necessary, adjust the volume collected at the next sampling period.

Collection Procedures

Unless otherwise specified for a given sampling area, three samples of old growth and three of new growth material (as long as they are distinguishable) will be collected for each species at each sampling period. *Do not* mix species or old and new growth in the same sample container. Collect the old and new growth samples in pairs, each sample pair containing material from approximately one third the accessible shrubs along the collection routes; thus, all shrubs will be represented about equally in the three pairs of samples.

Collect twigs and foliage only from the upper half of the shrubs. Each sample should contain nearly equal amounts of material from all sides and tops of the shrubs, but it is not necessary to collect material from all parts of each shrub. A properly selected sampling area will contain enough shrubs so that only a few twigs need to be taken from each during a sampling period. Consequently, taking twigs from all sides and the top of each shrub will likely produce too much material. If twigs are taken from the north side of one shrub, collect from the south side of the next, the east side of the next, and so on until the sample is completed.

After removing unwanted material from each twig, cut it into pieces 2 or 3 inches long so that the material fits easily into the container. The fuel pieces should be arranged to fill the container evenly. *Do not* compress the sample; drying times are based on loosely arranged fuel. The fuel begins to lose moisture as soon as it is removed from the shrub, so keep the container lightly sealed except when material is being added. After the sample is completed, brush off any debris from around the

sealing lip of the container and seal it tightly. (Make sure the lid and container numbers match.) The containers can best be sealed by putting them on the ground or other solid surface and then pressing the lid on firmly and evenly with the plywood disk. *Do not* pound the lids onto the containers with any solid object — the lid and container are likely to be damaged beyond further use. Record the required sampling data on the collection record form as samples are collected.

After all samples have been collected, put them in the portable ice chest for transport to the sample processing center. Place the chest in a part of the vehicle where it will not receive direct sunlight or cover it with a blanket or tarpaulin. If the containers become too hot, enough air pressure may develop to loosen the lids or the samples may begin to decompose in the hot, moist atmosphere in the containers. It is important that samples be weighed as soon as possible after collection, preferably within 2 or 3 hours. Before leaving the sampling area, complete the following: (1) observe the wet and dry bulb temperatures with the sling psychrometer and record these data along with the amount of cloudiness on the collection record form, and (2) circle the descriptions that best describe the physical condition of growth on the plants just sampled *(fig. 4)*. This is an average condition; do not be influenced by a few uncharacteristic situations. Use the following definitions:

New growth:

Starting — First appearance of new leaves or flower buds. Depending on the species sampled, flowering may be the first indication of the beginning of growth.

Continuing — New growth or flowering has progressed enough to provide more than a ½-inch new growth on most growing stems, or most flowers are developing seeds. Starting and continuing may both be circled.

Complete — New growth and flowering is complete. Old growth is no longer distinguishable from new growth.

None — Growth completed was shown at some previous sampling. No growth or very little growth is occurring.

Flowering:

Starting — First appearance of flowering, only occasional flowers are seen. This stage may be observed on more than one sampling date.

Peaking — Flowers are observed on most flowering stems. Starting and peaking can occur on the same sampling date and can be observed more than one time.

Declining — Few new flowers are seen and some flowers are turning color, dropping petals, or dropping intact. In a few instances, both peaking and declining may occur.

Drying—New flowers are absent or rare. Nearly all flowers are turning color or dropping. Declining and drying may occur together in some seasons.

None—Flowers are absent or isolated on a few unusual plants. If a few plants have some flowers, make a note under remarks.

Fruit:

Presenting—Seeds, berries, or nuts can be seen but most are green and/or soft.

Ripe—Seeds, berries, or nuts appear to be mostly ripe and are beginning to fall.

Fallen—Most seeds, berries, or nuts are gone.

None—Fruit is gone or is rare and isolated to a few plants.

DETERMINING FUEL MOISTURE[1]

Equipment

1. Laboratory drying oven—see note below
2. Laboratory balance with a direct reading to 0.1 gram
3. Paint can opener
4. Moisture determination record forms *(fig. 4)*
5. Set of balance weights *(fig. 9)*

Procedures

1. Weigh the *sealed* samples to the nearest 0.1 gram to obtain the gross weight *wet*. Record this under the gross weight wet, column A, on the record form. The samples should be weighed immediately after they are brought in from the field and *before* the container lids are removed for any reason. Clean the containers of any dirt and dust before weighing them, paying particular attention to the grooves around the lid and top of the container.

2. Carefully remove the container lids after the samples have been weighed.[2] Using the paint can opener, pry the lids up slowly around

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[1]The procedures are established for moisture determination using a mechanical convection oven and metal paint can-type sample containers. See appendix if convection ovens or glass sample containers are used.

[2]If the samples are not dried the same day they are collected, see appendix A for storage instructions.

Figure 9—Set of balance weights.

the perimeter to minimize distortion. Set the lids aside; they do not need to be placed in the oven.

3. Set the oven between 103° and 105° C (217° to 221° F) and preheat it for at least 1 hour at this temperature before placing the samples inside. Place the *open* containers in the drying oven. The oven temperature will decrease by 15 to 25 degrees because of heat absorption by the samples and the cooling effect of the evaporating moisture. It is not necessary to adjust the oven controls to compensate for this temperature change. A properly adjusted oven will regain the correct temperature as the samples are heated.

Do not overload the oven. Too many samples in the oven at one time will slow the drying process, result in nonuniform drying of samples, and may cause the oven controls to fail to maintain the proper oven temperature. Allow approximately 40 square inches of shelf space for each sample, and space the samples about equal distances apart and from the oven walls. If only one shelf is used, it should be placed so that the sample containers are near the middle of the oven. When using more than one shelf, the samples should be at least 3 inches from the bottom of the oven and not closer than 3 inches from the top. The space between containers on different shelves should be at least 1½ to 2 inches.

4. Dry the samples in the oven for 15 hours.[3] Avoid opening the oven door during the drying period, since the oven temperature will drop substantially each time the door is opened. However, the oven vent must always be fully open during the drying period to allow moisture to escape.

5. Remove the samples from the oven at the end of the drying period. Use gloves, since the containers will be hot. Seal each container immediately after it is removed, making sure that the container lid and container number match. The very dry fuel quickly absorbs moisture from the air, so it is important that sample removal and sealing be done rapidly.

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[3]See footnote 1.

6. Allow the sealed samples to cool to room temperature. The warm containers create convection currents that cause large weighing errors if samples are weighed before they are cooled.

7. After the samples have cooled, weigh them to the nearest 0.1 gram. Record this weight in the gross weight *dry,* column B, of the record form.

8. Put aside the unopened weighed samples until after the moisture content computations have been made.

Moisture Content

The moisture content of the samples is obtained from the equation:

$$\text{Percent moisture} = \frac{\text{Sample weight loss}}{\text{Sample dry weight}} \times 100$$

Remember that moisture content for living chaparral fuels is expressed as a percentage of dry weight. Solution of the equation requires the following steps (an example is shown on the sample record form, *fig. 4*):

1. Record the empty container weights in column C, on the moisture determination record form. If the container weight is not marked on the container, secure it from the container weight record.

2. Subtract the empty container weight, column C, from the gross weight *dry,* column B, to obtain the *dry* weight of the sample. Record this dry weight in column D on the record form.

3. To determine the sample weight loss, subtract the gross weight *dry,* column B, from the gross weight *wet,* column A. Record the weight loss in column E on the record form.

4. Divide the weight loss, column E, of each sample by its dry weight, column D. Carry this calculation to three decimal places.

5. Multiply the quotient obtained in step 4 by 100 by moving the decimal point two places to the right. The result is the moisture content of the sample in percent, and this value is to be recorded under percent moisture, column F, of the record form.

6. If any samples have a dry weight in excess of 50 grams or an indicated moisture greater than 275 percent, it is possible that they are too compact or moist to dry completely in 15 hours. Open such samples and dry them an additional 6 hours in the oven. Repeat steps 5 through 7 of the drying procedures, then recalculate the moisture content.

Preparing Containers for Reuse

1. Sample containers may be emptied after the moisture computations have been completed. Make sure that all fuel particles are removed. The interior and exterior of the containers usually can be wiped clean with a damp cloth. Occasionally, however, pieces of foliage may adhere to the sides or bottom of the interior—this occurs most frequently with new growth samples. Soaking the containers in soapy water may be necessary to remove this material.

2. Inspect the containers and the sealing lips on lids. Discard any damaged lids or containers. From the remaining lot, match as many good lids and containers as possible. Once this is done, remove the numbers and any weight markings from both the lid and container. Renumber and reweigh the container and lid.

3. Ensure that all containers are thoroughly dry, then replace the lids tightly enough so that they will stay in place while being transported to the field. Make sure that the lid number and container number match.

Care and Use of Laboratory Balances

Accuracy of fuel moisture determination by oven drying is highly dependent on precise weight measurements. In the foregoing procedure, weights must be determined to the nearest 0.1 gram. This is a very small unit of weight (a single manzanita leaf weighs between 0.1 and 0.2 gram). Weighing to the necessary degree of accuracy is not difficult, but special heed must be given to minimizing external influences that affect weight measurements.

The balance must be set up on a level, solid surface. A balance will not weigh accurately if it is not level, and vibration will make accurate weighing difficult or impossible. Place the balance where it will not receive direct sunlight, and in a part of the room that is free of air currents, such as those from heating and air conditioning vents or open windows and doors. A corner of a room is often a suitable location for the balance. A corrugated paper box can also be used to provide a still-air environment for weighing. The box should be large enough to house the balance and provide sufficient room to weigh the fuel samples. Remove the top flaps from the box. Place the box on its side with the opening toward the observer. Cut a piece of plywood or similar material slightly smaller than the box and put this inside the box to provide a solid surface on which to place the balance. The corrugated paper tends to compress somewhat under the weight of the balance and may make

leveling and zeroing of the balance difficult if the hard surface insert is not used.

Check the zero setting of the balance before each weighing session and adjust it according to the manufacturer's directions, if necessary. Recheck the balance zero after each five or six samples are weighed; the zero on some balances tends to change slightly with temperature variations and as the balance is "exercised."

Before placing the sample container on the balance, make sure that the weighing pan is clean. Always center the sample container on the weighing pan. Beam-type balances usually have notches on the beams for proper placement of the major weights, and all of these weights must be in a notch. Even a slight misplacement of the weights will cause a large error. Double check the weight reading before recording it on the record form. Misreading the balance is one of the most common causes of weighing errors.

A properly used quality balance will seldom need accuracy adjustments. However, an inaccurate balance is not easily detected in normal weighing operations; consequently, its accuracy should be checked periodically. This is done by weighing standard balance weights on the weighing pan. Check the balance reading near the low and high ends of its range and at least one point between. If the balance is inaccurate, make adjustments according to the manufacturer's instructions or return the balance to the manufacturer for adjustment or repair.

A laboratory balance is a delicate instrument and should be kept covered when not in use to protect the bearings and knife edges from dust and dirt. Avoid frequent moving of the balance from place to place.

APPENDIX

A. Drying Time Adjustments

1. If 1-quart glass canning jars are used for sample containers, increase the basic drying time of the samples to 18 hours for a mechanical convection oven.

2. The basic drying time for samples in metal containers placed in a gravity convection oven is 18 hours. Increase this drying time to 21 hours if 1-quart glass canning jars are used for sample containers.

B. Sample Storage

Best results will be obtained when the sample drying process is started on the same day that the samples are collected. If this is not possible, the samples may be stored for short periods as follows:

1. Weigh the sealed containers and record the weight in the gross weight wet column of the record form. The sample containers should then be opened. Samples in open containers can be stored up to 48 hours at room temperature and up to 5 days in a refrigerator. Do not reweigh the samples when they are placed in the oven for drying; weight loss during storage will appear as part of the weight loss in the oven. Samples that cannot be processed within 5 days after collection should be discarded.

2. Samples that cannot be weighed the day they are collected may be stored unopened in a refrigerator for periods up to 24 hours. Allow the samples to warm to room temperature before they are weighed. Make sure that there is no condensation on the exterior of the container. Discard samples that are not weighed within 24 hours.

C. Checking Oven Temperatures

Temperature within most laboratory drying ovens is monitored with a mercury-in-glass thermometer inserted in top or side of the oven. Thermometers are of the long-stemmed type, with a mark indicating the portion of the thermometer that should be within the oven cavity.[4] Moni-

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[4]Some low-cost ovens may be equipped with standard mercury-in-glass thermometers. These thermometers should be inserted into the oven so that the bulb is at least 3 inches from the oven's interior top or wall.

toring thermometer should be left in place while drying the fuel samples.

Temperature control on most ovens is marked with numbers or letters for different temperature settings or may only have an arrow to indicate which direction to adjust the control for a higher or lower temperature. For convenience in using the oven to dry fuel samples, the control should be marked at the setting that will give 104° C (220° F) on the monitoring thermometer. Oven temperature should be checked each time, as a small adjustment of the control may be needed to attain the correct drying temperature.

Temperature of the modern mechanical convection oven of good quality is quite uniform over most of the oven cavity. Therefore, samples loaded in the oven as specified in the drying procedures will be subject to the same temperature. Convection drying ovens, however, often have large temperature variations within the cavity, particularly older and many low cost ovens. Temperature variation of such ovens must be checked before they are used to dry fuel samples, as part of the oven volume may not be within allowable temperatures.

An electrical temperature probe with a strip chart recorder is best suited for checking temperature variations in the ovens. The following procedure is used:

1. Insert the probe to the center of the oven cavity.
2. Turn on the oven and adjust the control to give a temperature of 104° C (220° F) at that point. The recorder trace will show an initial rapid rise in the oven temperature. The indicated temperature will then vary by 2 or 3 degrees around the set point as the heating element is cycled on and off by the control. Use the average temperature in this latter variation to establish the proper control setting.
3. Allow the oven temperature to stabilize for at least 1 hour after the final adjustment of the control.
4. Using the probe, make temperature measurements along a vertical line at the center of the oven at 2-inch intervals, beginning 2 inches from the bottom of the oven and ending about 2 inches from the top. Also, make a temperature measurement at the level of the bulb of the monitoring thermometer. Leave the probe at each point through 4 or 5 on-off cycles of the heating element, and clearly mark the location of the probe on the recorder trace. *Do not* change the temperature control setting during these measurements.
5. Make similar temperature measurements along a vertical line 2 inches from one wall of the oven, and also along a vertical line midway between the center and that line.
6. Determine the average temperature at each point from the recorder trace.

7. Drying temperatures of the fuel samples should not vary by more than 3 °C (6 °F) from the standard temperature of 104 °C (220 °F). The temperature in the oven cavity is usually fairly symmetrical around the center point; therefore, the three lines of temperature measurements can be used to establish the usable volume by interpolating between the measured temperatures. This process is facilitated by plotting the temperature measurements on a scale drawing of the oven cavity. Use the temperature obtained at the level of the monitoring thermometer bulb to establish the thermometer reading that will give the proper operating temperature at the center of the oven. Post this temperature and the usable volume of the oven near or on the oven.

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California Wildlife and Their Habitats: Western Sierra Nevada

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The relationships between 355 wildlife species and their habitats are examined in a series of matrices, life history notes, and distribution maps covering 26 amphibians, 27 reptiles, 208 birds, and 94 mammals. The information is useful in identifying and evaluating the consequences of proposed land management activities—particularly those that manipulate vegetation. Although designed for use by land managers, the publication provides information useful to both professionals and lay persons interested in California wildlife.

Retrieval Terms: habitat management, amphibians, reptiles, birds, mammals, conifer forests, annual grasslands, oak woodlands, riparian deciduous, mountain meadows, Sierra Nevada, California.

California Wildlife and Their Habitats: Western Sierra Nevada

Jared Verner, Allan S. Boss, *Technical Coordinators*

Contents

Issued January 1980

Preface

This report is one of a series from the California Wildlife Habitat Relationships Program sponsored by the California (now Pacific Southwest) Region, Forest Service, U.S. Department of Agriculture, in cooperation with the Pacific Southwest Forest and Range Experiment Station; Fish and Wildlife Service and Bureau of Land Management, U.S. Department of the Interior; California Department of Fish and Game; Nevada Department of Fish and Game; and the Southern California Edison Company. The initial stimulus for the Program came from the development of guidelines for management of wildlife species in the Blue Mountains of Oregon and Washington (Thomas 1979).

The program is seeking to develop a system for providing land managers with quantitative information on the responses of wildlife species to land management alternatives on the forests and rangelands of California and parts of Nevada. Its aim is to apply the knowledge of habitat requirements of wildlife species in identifying and evaluating the consequences of proposed land management activities—particularly those activities that manipulate vegetation. It is designed specifically to help improve wildlife planning by land managers. It is not intended to set management policy. That is the manager's responsibility, given knowledge of the consequences of available options.

The Program area is divided into four zones (*fig. 1*). Each zone has a Working Group responsible for identifying the wildlife species, habitat types, and interrelationships applicable to the ecological attributes of the zone. Each group is developing for its zone a matrix showing relationships of wildlife to habitats, notes on life history, and a distribution map for each species.

This volume covers Zone 1—The Western Sierra Nevada. Its boundaries are: north—boundary between Shasta and Siskiyou Counties; east—Sierran Crest; south—Kern Gap (State Highway 178); and west—the 1000-foot (305-m) elevation contour.

Management documents for selected habitats and wildlife species are also being developed for the Program area as a whole.

The approach taken is to rely on specialists to provide the necessary wildlife information, based on their personal field experience, consultation with experts, and review of the appropriate literature. These specialists are Harold E. Basey, Modesto Jr. College (amphibians and reptiles), Edward C. Beedy and Stephen L. Granholm, University of California, Davis (birds), and Dr. Marshall White, University of California, Berkeley (mammals).

The information in the publication has been stored on a computer accessible through the California (now Pacific Southwest) Region, Forest Service, San Francisco. Ways are being explored to use the computer for efficient application of the extensive data base to land management decisions. A description and explanation of the methods finally adopted will be published as a product of the Program.

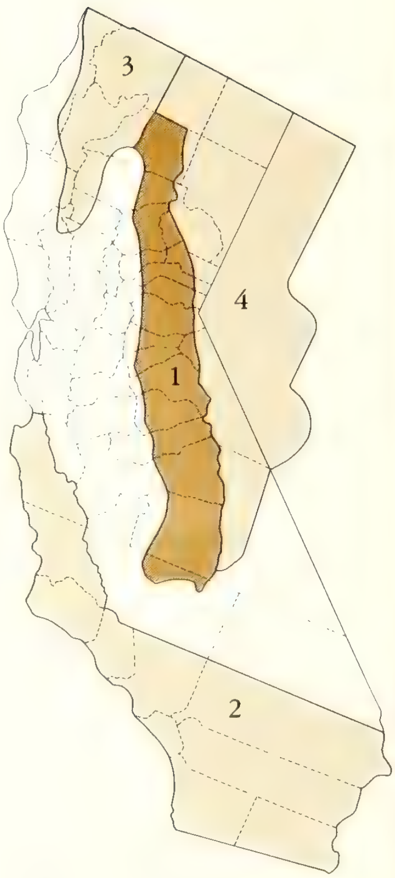


Figure 1–*The California Wildlife/Habitat Relationships Program is divided into four zones: 1 (Western Sierra Nevada), 2 (Southern), 3 (North Coast), and 4 (Eastside). The Eastside Zone includes a portion of Nevada.*

Introduction and Scope

Jared Verner and *Allan S. Boss*

The Forest Service, U.S. Department of Agriculture, is mandated by law to manage its lands in a manner that assures the conservation of all animal species. The Multiple Use-Sustained Yield Act of 1960, the Endangered Species Act of 1973, the Forest and Rangeland Renewable Resources Planning Act of 1974, and the National Forest Management Act of 1976 all explicitly recognize animals as among our important, renewable natural resources. This statutory requirement poses a formidable assignment, as thousands of species of animals are found in National Forests throughout the United States. Even within a single National Forest the number is likely to run into the hundreds, just considering vertebrate species alone.

Adequate assessment of the potential responses of all these species to alternative land and resource management programs requires an up-to-date data base on the habitat requirements and basic life history of each species. The biological literature on animal life histories and habitat requirements is voluminous, but it falls short of being adequate for the assessment needs. It nonetheless provides a substantial foundation for arranging information in a form useful as a tool in considering the consequences of alternative management options.

This publication has assembled in such a form biological information about the amphibians, reptiles, birds, and mammals regularly found on forest and range lands of the western Sierra Nevada of California.

Species Included

Notes on life history and habitat requirements of 355 species, grouped by taxonomic class, are included in this publication. The species within each group are arranged in phylogenetic order, and each has been assigned an alphanumeric code for purposes of cross referencing and for obtaining access to computer-stored data on each species. Reference codes for the groups of species are:

Group	*Species*	*Reference Codes*
Amphibians	26	A001 through A026
Reptiles	27	R001 through R027
Birds	208	B001 through B208
Mammals	94	M001 through M094

An additional 57 bird species that show only "accidental" occurrence in the zone are not treated in detail here, but are listed in the section on Rare Species in the *Bird* chapter.

Species/Habitat Matrices

Species/habitat matrices display information in a simple, straightforward, tabular format that can be learned in a matter of minutes (*fig. 2*). Some time should be spent on becoming familiar with the elements of the matrices, because they form the single most important part of the publication.

Species

The species are arranged in the same phylogenetic sequence as the text notes and are identified by the same alphanumeric codes. The page number of the notes and distribution map for each species is shown in a separate "Page" column of the matrix.

The Pacific Southwest Region of the Forest Service has established the following *Emphasis Species* priority for management:

1. *Recovery Species*: species in these categories are identified in the name block of the matrix.
   a. *Endangered Species*: any species threatened with extinction.
   b. *Threatened Species*: any species likely to become endangered within the foreseeable future, throughout all or a significant part of its range.
   c. *Rare Species*: same as a Threatened Species (this is a State of California classification).
   d. *Sensitive Species*: any species, as designated by the Regional Forester, Pacific Southwest Region, that is under study for classification as Threatened, Endangered, or Rare, or that has a low population density or highly restricted range for which National Forests make up a significant portion of the available habitat.
2. *Harvest Species*: species subject to sport or commercial harvest under regulations of the California Fish and Game Commission.
3. *Special Interest Species*: nonharvest species of special public interest that were formerly referred to as "unique."

All other species are recognized as *Maintenance Species.*

Special Habitat Requirements

These requirements are entered in the next block. *Items included here are deemed to be essential for a given species to occur regularly or to reproduce.* Many of these items, such as trees, shrubs, stumps, old buildings, and willow thickets, require no definition or explanation. Others, however, need further clarification. These are listed and defined below under substrate, aquatic, vegetation, and miscellaneous elements.

Substrate Elements

- *Ground burrows*: Burrows excavated by species other than those for which they are special requirements.
- *Friable soil*: Relatively soft, crumbly soil suitable for burrowing; this wili also generally be a well-aerated soil.
- *Sand*: Substrate of nearly pure sand, or sandy banks along streams.
- *Moist soil*: Surface area damp to wet but not saturated, occurring near springs, seeps, streams, ponds, or other aquatic sites.
- *Earthen banks*: Road cuts, stream banks, and other areas of nearly vertical, exposed soil suitable for burrowing.
- *Rock outcrops*: Fairly substantial outcrops with large boulders and plenty of hiding places.
- *Caves*: Areas suitable for roosting or hibernation or both, including mines and other human excavations resembling caves.
- *Limestone outcrops*: Moist outcrops of limestone essential to certain species of amphibians.
- *Talus*: Sloping mass of rock fragments commonly found at the base of a cliff.
- *Cliffs*: Steep rock faces of varying size, which are required by many species for nest placement—mostly on ledges or in recesses.
- *Crevices*: Larger cracks in cliffs and smaller rock faces.

Aquatic Elements

- *Water*: Any unspecified water source, even stock watering tanks, typically required for drinking or bathing.
- *Seeps*: Areas of underground water seepage that saturate the soil, generally over a fairly large area.
- *Springs*: Point sources of water flow from underground; they may or may not occur together with seeps.
- *Streams or rivers*: Moving water courses of any width. Streams are smaller than rivers although no precise separation between these categories is intended here.
- *Permanent streams* (or *rivers*): Those that maintain water flow year round.
- *Pools in permanent streams* (or *rivers*): Those having reduced rates of water flow and at least 3 ft (1 m) deep.
- *Ponds*: Standing bodies of water with less than 1 acre (0.4 ha) of surface area.
- *Lakes*: Standing bodies of water with 1 acre (0.4 ha) of surface area or more.
- *Marshes*: Substantial patches (at least 1 acre [0.4 ha]) of emergent vegetation, usually cattails (*Typha*) or bulrush (*Scirpus*), along the margins of ponds, lakes, streams, rivers, or in wet meadows.

Vegetation Elements

- *Forest openings*: Areas in otherwise fairly dense stands where most or all of the tree canopy is missing for any reason; may be covered with grasses and forbs only, or may have some shrub cover, not exceeding 50 percent.

  Small openings—Less than 1 acre (0.4 ha) in extent.

  Medium openings—From 1 to 5 acres (0.4 to 2 ha) in extent.

  Large openings—Larger than 5 acres (2 ha) in extent.
- *Trees/shrubs*: Interspersed patches of shrubs and trees.
- *Trees/grass-forbs*: Interspersed patches of trees and grass and/or forbs.
- *Shrubs/grass-forbs*: Interspersed patches of shrubs and grass and/or forbs, as often develop in early succession or in ecotones.
- *Snags*: Standing, dead or partially dead trees at least 11 inches (28 cm) dbh and 12 ft (3.7 m) high.
- *Elevated perches*: Places in trees, shrubs, or snags, or on fence posts, power poles, buildings, or any other spot affording a view of the surrounding terrain.
- *Nest cavities*: Natural or excavated cavities in living or dead trees, suitable for shelter or nesting by birds or small mammals.
- *Hollows*: Provided by hollow logs, hollow bases of trees, openings created at the bases of upturned roots of fallen trees, or any other such openings large enough to shelter larger animals.
- *Logs*: Downed boles at least 10 inches (25 cm) in diameter at the large end, recently fallen to meet the cover needs of some species, or in advanced stages of decomposition and moist near the ground, to meet needs of other species.
- *Litter*: Downed and decaying bark, foliage, twigs, branches, and smaller stems providing substantial cover of the ground, at least in patches.

Miscellaneous Elements

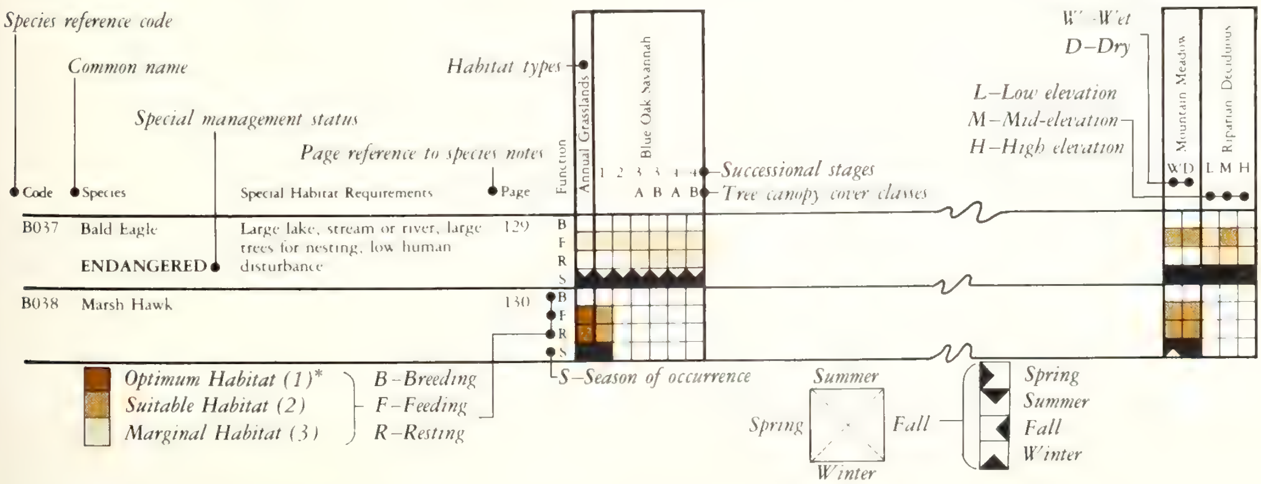
- *Open Terrain*: Extensive open areas, not necessarily surrounded by forest, although forests may form an ecotone along one or more sides of such terrain, including extensive alpine meadows above treeline and expansive annual grasslands at low elevations.
- *Low human disturbance*: Any sort of human intrusion into a habitat. (It is not possible here to set quantitative limits on human disturbance; each case must be considered individually and evaluated in the context of what is known of the species.)

Habitat Stages

A *habitat stage* is identified by its particular combination of habitat type, successional stage, and percentage canopy closure. Seventy different habitat stages are recognized here.

Habitat Types—The habitat types are based largely on those found in *Forest Cover Types of North America* (Society of American Foresters 1954) with some modifications adopted to reflect what is known of animal species distribution and habitat selection. These types are translatable into all other vegetation classification systems commonly used today on National Forests of California. The habitat types listed here generally tend to occur at lower elevations in the northern than in the southern Sierra Nevada.

- *Annual grasslands*: Dominated by wild oats (*Avena* spp), rip gut (*Bromus rigidus*), soft chess (*Bromus mollis*), bur clover (*Medicago hispida*), and filaree (*Erodium* spp), with less than 5 percent shrub and/or tree canopy.
- *Blue oak savannah*: Characterized by annual grassland understory with scattered blue oak (*Quercus douglasii*).
- *Digger pine-oak*: Dominated by digger pine (*Pinus sabiniana*) and blue oak, with lesser amounts of interior live oak (*Quercus wislizenii*). Understory vegetation consists of mixtures of mariposa manzanita (*Arctostaphylos mariposa*), buckbrush (*Ceanothus cuneatus*), redberry (*Rhamnus crocea*), California coffeeberry (*Rhamnus californica*), western mountain mahogany (*Cercocarpus betuloides*), other shrub species and annual grasses and forbs. This type ranges generally from about 300 to 2000 ft (91 to 610 m) in elevation.
- *Chaparral*: Characterized by mixtures of mariposa manzanita, western mountain mahogany, buckbrush, dwarf interior live oak (*Quercus wislizenii*, var. *frutescens*), California scrub oak (*Quercus dumosa*), chamise (*Adenostoma fasciculatum*), and poison oak (*Rhus diversiloba*). The shrubs occur in dense to highly dense stands with little herbaceous understory. Elevation ranges from 1000 to 5000 ft (305 to 1520 m). Higher altitude brush fields are not included here in the chaparral type, but are treated as early successional stages of forest types.
- *Ponderosa pine*: Ponderosa pine (*Pinus ponderosa*) contributes over 80 percent of the stand, with white fir (*Abies concolor*) and black oak (*Quercus kelloggii*) present in amounts up to 20 percent. Sugar pine (*Pinus lambertiana*) mixes with ponderosa pine on better sites, while incense-cedar (*Calocedrus decurrens*), Douglas-fir (*Pseudotsuga menziesii*), and small amounts of white fir also may be present in the higher parts of the type. Elevation ranges from 2000 to 5000 ft (610 to 1520 m).
- *Black oak woodland*: Characterized by dense to rather open stands of black oak and associated hardwoods, with minor amounts of ponderosa pine or Douglas-fir, or both, and sometimes incense-cedar and white fir. The shrub understory is usually sparse, but may be quite dense in openings. Frequency and proportion of associated hardwoods increase as site quality declines, as on southern slopes or areas with less precipitation. They include canyon live oak (*Quercus chrysolepis*), bigleaf maple (*Acer macrophyllum*) (on wetter sites), and Pacific madrone (*Arbutus menziesii*). Characteristic understory species include poison oak and deer brush (*Ceanothus intergerrimus*).



Numbers to be used for computer coding of habitat quality designations.

Figure 2—*The key to elements in the species/habitat matrix is found in the sample. For an explanation of the codes used, and definitions of the elements, see the subchapter on Species/Habitat Matrices.*

Although black oak occurs throughout the western Sierra Nevada, typical black oak woodlands, as characterized here, are primarily restricted to the northern portion of the mountain range.

- *Mountain meadow*: Occurs in openings interspersed among the various timber types. Generally there is less than 20 percent shrub canopy, and trees may occur widely scattered, especially around the perimeters. Two meadow types—wet and dry—are recognized in this classification, although commonly both types may occur in the same opening. Wet meadows typically occur above 3900 ft (1200 m) in the north and 5900 ft (1800 m) in the south (Rundel *et al.* 1977). They support perennial sedges, rushes, and grasses (Cyperaceae, Juncaceae and Graminae). The soil is likely to remain wet late into the summer and in some places permanently. Willows (*Salix* spp) and alders (*Alnus* spp) may form rather dense thickets about these wetter sites. Dry meadows are dominated by perennial grasses and forbs, and most will have some sedges.
- *Riparian deciduous*: Occurs at most elevations where stream or pond conditions provide sufficient moisture for a narrow band of deciduous trees and shrubs along the margins. Three elevational categories are distinguished here: (1) Low elevation riparian deciduous (L) occurs generally downslope from the ponderosa pine forests; characteristic tree species are cottonwoods (*Populus*), California sycamore (*Platanus racemosa*), and willows. (2) Mid-elevation riparian deciduous (M) is approximately coincident with the mixed-conifer forest zone; characteristic species are white alder (*Alnus rhombifolia*), bigleaf maple, willows, California hazelnut (*Corylus rostrata*), western azalea (*Rhododendron occidentale*), and creek dogwood (*Cornus stolonifera*, var. *californica*). (3) High elevation riparian deciduous (H) is found generally above mixed-conifer forests; willow is the typical woody form in this type.
- *Mixed conifer:* Predominantly a five-species mixture of white fir, incense-cedar, sugar pine, ponderosa pine, and Douglas-fir, typically found from about 3000 to 6000 ft (915 to 1830 m) elevation. Other conifer species occur more sparingly, including lodgepole pine (*Pinus contorta*), Jeffrey pine (*Pinus jeffreyi*), red fir (*Abies magnifica*), and in a few restricted localities even giant sequoia (*Sequoiadendron giganteum*). The mixtures are exceedingly variable, with white fir dominating on north exposures and at higher elevations, and ponderosa pine tending to dominate at lower elevations and on drier sites. Sugar pine and incense-cedar are widely distributed but rarely dominate. This type includes what some authorities refer to as the "white fir" type.
- *Jeffrey pine*: Jeffrey pine is the dominant species, with limited numbers of white fir. Ponderosa pine is often present in substantial numbers and many species, such as red fir, sugar pine, lodgepole pine, and black oak may be present in small numbers. Elevation ranges from about 3500 to 9000 ft (1070 to 2740 m).
- *Red fir*: Red fir occurs in pure stands or predominates in mixed stands with white fir. Jeffrey pine occurs on the more arid slopes, while western white pine (*Pinus monticola*) and lodgepole pine are included at higher elevations. At lower elevations, sugar pine is rather characteristically intermingled. This type occurs from 6000 to 9000 ft (1830 to 2740 m) elevation.
- *Lodgepole pine/mountain hemlock/whitebark pine* (shown on matrix heading as "lodgepole pine"): This conglomerate makes up the highest elevation forests, extending from the upper margins of the red fir zone up to timberline. Lodgepole pine is most often the dominant species, but western white pine, Jeffrey pine, and red fir may intermingle in varying amounts. Pure to nearly pure stands of mountain hemlock (*Tsuga mertensiana*) may occur on north-facing slopes, and at higher elevations whitebark pine (*Pinus albicaulis*) may occur in relatively pure stands. Lodgepole forests also occur in places at lower elevations, as in the red fir zone, where soil and moisture conditions are suitable. Here they may have a distinct fauna.
- *Alpine meadow*: Occurs above treeline. Sedges and other grasslikes (for example *Heleocharis* and *Scirpus*) comprise the chief dominants, with perennial grasses (especially *Calamagrostis breweri*) and forbs in varying mixtures comprising the remainder.

Successional Stages—Time, nature, and human activities bring changes in the structure and composition of a plant community that are reflected by changes in associated animal communities. To an extent these changes may be handled by recognizing successional stages of the various habitat types. The classification of successional stages usually implies a natural progression toward more mature stages, such as large trees or dense shrubs. Sometimes, however, ecological factors such as soil type or exposure may function to keep a stand of vegetation at a "lower" stage. In our classification, one would treat such a stand as a successional stage for determining wildlife associations. Mountain chaparral, for example, may be treated as a shrub stage of the predominating surrounding forest type. In projecting future for-

est habitats, it must not be assumed that such stands will progress toward big trees or dense shrubs.

Successional stages of tree and chaparral habitat types are identified numerically in the matrices; these are defined below. We have not differentiated successional stages for annual grassland, riparian deciduous, mountain meadow, or alpine meadow types.

- Successional stages of tree habitat types (*fig. 3*):
  1 (*Grass/forb stage*): Consists of annual and perennial grasses and forbs, with or without scattered shrubs and seedlings.
  2 (*Shrub/seedling/sapling stage*): Has mixed or pure stands of shrubs, tree seedlings, and tree saplings up to about 20 ft (6.1 m) in height.
  3 (*Pole/medium tree stage*): Includes larger trees, in the size range 20 to 50 ft (6.1 to 15 m) in height.
  4 (*Large tree stage*): Corresponds roughly to the mature and overmature classifications of foresters. Trees generally exceed 50 ft (15 m) in height, except perhaps with some of the oak types—especially at lower elevations.
- Successional stages of chaparral habitat:
  1 (*Grass/forb stage*): Essentially the same as the grass/forb stage of tree habitat types.
  2 (*Light shrub stage*): Has less than 50 percent canopy cover.
  3 (*Dense shrub stage*): Has 50 percent or greater canopy cover.

Tree Canopy Closure Classes—The extent of a shrub layer is paramount in the habitat selection of many animal species, particularly birds. The present classification omits direct reference to percent shrub cover, but the division of successional stages by percent canopy coverage deals indirectly with the question of shrub cover, because the growth of a shrub layer is related to the amount of sunlight able to pass through the canopy. Three canopy closure ratings are coded alphabetically for successional stages with trees in the species/habitat matrix (*fig. 4*).

A: Total tree canopy cover from 0 to 39 percent; stands in this category commonly support a substantial shrub layer.

B: Cover from 40 to 69 percent. The shrub layer is variable but usually present in the class B stands.

C: Cover 70 percent or greater; typically little shrub layer is present under such a canopy. (Class C ratings are not included in the matrix for blue oak savannah or black oak woodland, because these stands rarely, if ever, achieve 70 percent or greater canopy cover.)

Species Activities

Habitat utilization, by species, is rated separately for three major life history activities:

B: Breeding (note that this term for mammals refers to the period when young are born and being nurtured).

F: Feeding.

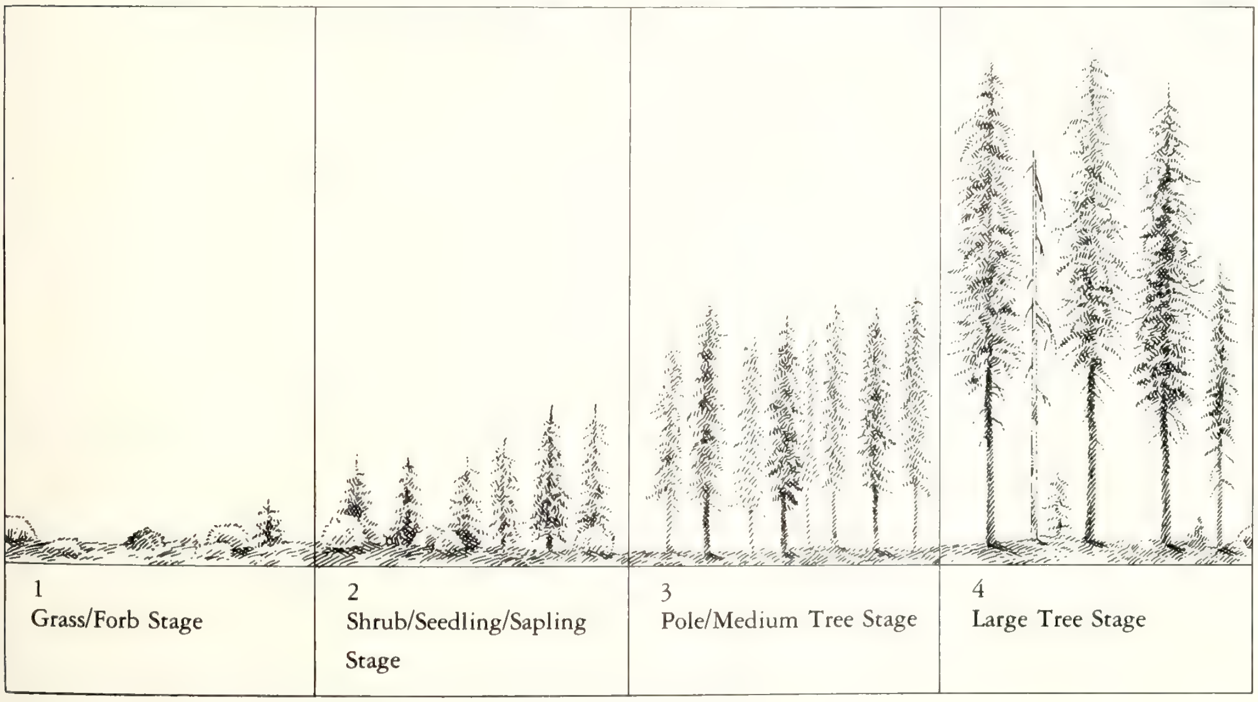


Figure 3—*Successional stages for forest types in the Sierra Nevada of California.*

Season of Occurrence

All blocks in these rows showing season of species' occurrence are divided into four triangles, each one corresponding to a season. A shaded triangle indicates that the species predictably may be found in that habitat stage during the season indicated (see *fig. 2*).

Left (spring): Approximately March through May.

Top (summer): Approximately June through August.

Right (fall): Approximately September through November.

Bottom (winter): Approximately December through February.

Habitat Suitability Rating

Suitability of each habitat stage for a given species was rated by the professional specialists, based on their review of the literature, their personal experience with the animals in the field, and opinions of others having field experience with the animals. Although these ratings are subjective, they nonetheless represent the best estimates currently available.

The habitat ratings are color-coded in the matrix. They also have been assigned ordinal number codes for ranking purposes associated with computer applications of the matrix information.

Dark brown, computer code number 1 (*Optimum habitat*): Best quality habitat for a species, as judged by high breeding density or frequency of use for feeding or resting cover.

Medium brown, computer code number 2 (*Suitable habitat*): Good habitat for the species, but not among the best, as judged by an intermediate breeding density or frequency of use for feeding or resting.

Light brown, computer code number 3 (*Marginal habitat*): As judged by observed animal density and/or frequency of use, habitat of this quality is used by the species, perhaps on a regular basis, but it does not contribute significantly over time to the maintenance of any population.

Species Notes

Pertinent details not included in the species/habitat matrices are summarized in notes covering each species. Information is arranged in these categories: status, distribution/habitat, special habitat requirements, breeding, territory/home range, other, and references. Information from studies in the Sierra Nevada, or at least in California, was used whenever possible. When such studies were unavailable, data from studies elsewhere have been included and the study localities identified. California localities are designated by county only in the Species Notes; the State is understood to be California. Otherwise, locality information identifies the State where a study was done. The literature search was extensive, but not exhaustive.

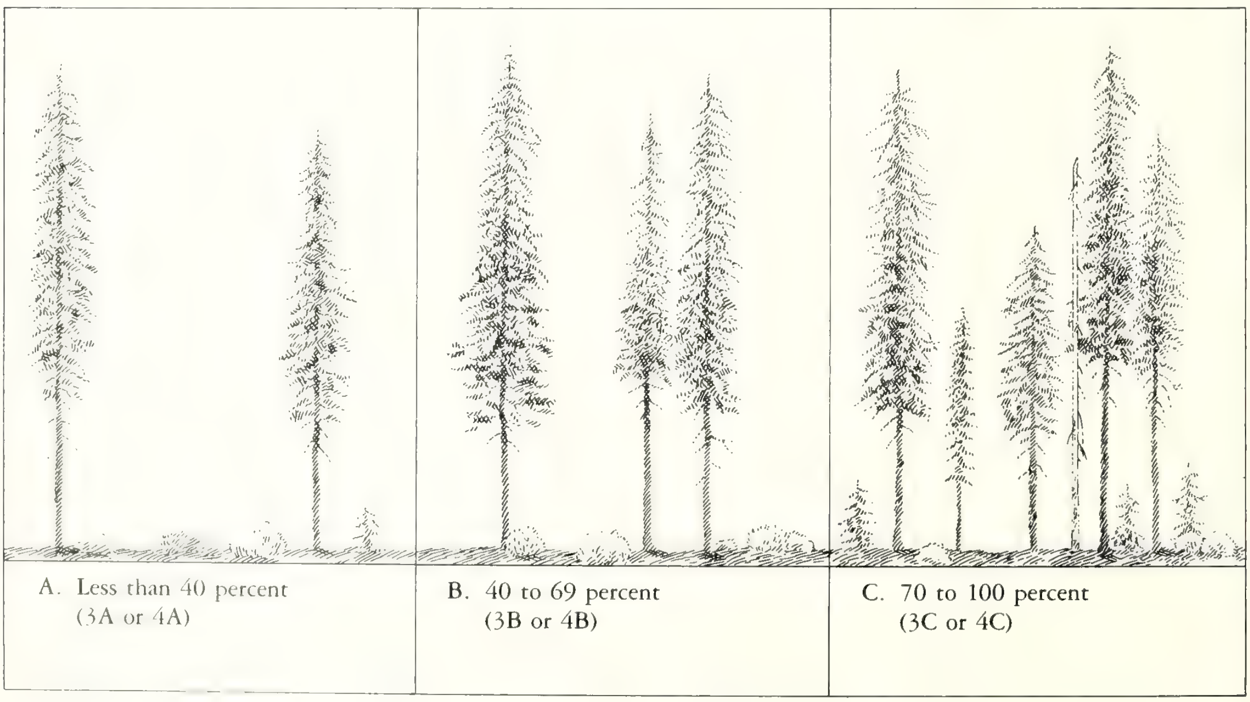


Figure 4—*Canopy closure classes for successional stages 3 and 4 in the Sierra Nevada of California.*

The **Status** of a species indicates whether or not it has been classified as to management significance and may include reference to any one of several possible classifications. The phrase "No official listed status" indicates that the species is not classified as Threatened, Endangered, or Rare by State or Federal agencies. The status of bird species is further qualified through reference to the National Audubon Society's "Blue List" for 1978 (Arbib 1977). This list is developed from information from regional authorities on birds throughout the United States. From observed trends in bird species numbers, they submit recommendations to the Society. Inclusion of a species on the blue list may be considered to identify species deserving special attention—species which may be candidates for future listing as Threatened or Endangered.

The **Distribution/Habitat** information summarizes data presented in the species/habitat matrix. All localities indicated in this section are understood to be in California. The **Special Habitat Requirements** information essentially duplicates that included in the species/habitat matrix, although some additional explanation may be added.

The section on **Breeding** gives information on breeding seasons (times of the year when young are produced and cared for); types of nesting, denning, or egg-laying sites; and numbers of eggs laid or offspring born. **Territory/Home Range** presents information on sizes of territories and home ranges, for both breeding and nonbreeding periods when available. **Other** is a miscellaneous category usually left blank, but sometimes providing specific management recommendations or other information of interest about the species.

The final category, **References**, cites literature on each species. The articles selected are among the most recent and contain references to the most useful articles on the species. They provide additional sources in the event further details about the species' life history are needed.

Distribution Maps

The approximate distribution of each species within the western Sierra Nevada is illustrated by a map. These maps show only the approximate boundaries of the zone covered by this report. Included counties are named.

Since amphibians, reptiles, and most mammals do not show any marked seasonal movements, their year-round distribution can be displayed by a single delineation. Distribution maps of the birds, however, are complicated by the altitudinal or latitudinal migration, or both, of most species. Therefore, maps for most bird species delineate separately their breeding distribution, their nonbreeding distribution, and their overlapping breeding and nonbreeding distribution *(fig. 5)*.

These maps can be used to determine whether a species is likely to occur within a county or National Forest. However, they lack the fine detail needed to permit close determination of occurrence. Moreover, in many instances it was necessary to infer substantial portions of a species' distribution from information on habitat preferences, since the published literature does not always include specific references to each county or forest within which a species has been observed.

Maps for some species display a star to identify the locality of a restricted breeding distribution. In some instances, perhaps only a single breeding record is available for the species. In all such cases, the particular breeding status is discussed in the notes.

Area where species typically does not occur.

Nonbreeding distribution, nonpermanent resident. Occurrence is seasonal only, as for migration or wintering.

Breeding distribution. Species not typically found here except shortly before, during, and shortly after the breeding period.

Year-round distribution. Breeding may or may not occur here.

Localized breeding record.

Figure 5—*Key to distribution codes for birds.*

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Using the Publication

Jared Verner and *Allan S. Boss*

Application of Data

If used properly, the information in this publication can effectively assist the land manager in assessing potential effects on animals of proposed habitat management activities, and in identifying management opportunities for wildlife species. In addition, it would allow the manager to formulate and evaluate with greater confidence alternatives for land and resource management planning, with reference to wildlife species. The information gathered puts wildlife habitat needs into practicable terms, so management objectives can be set, measured, cost assessed, and programmed over time.

The information reported is useful in forming judgments about potential responses of amphibians, reptiles, birds, and mammals to identifiable habitat changes in the western Sierra Nevada. It can all but eliminate the possibility of approving projects that might adversely affect Threatened, Endangered, or Rare species, or any other species worthy of special consideration. *But the application of this process is not a substitute for field work and sound biological and management judgment.*

The biologist still will need to conduct thorough field investigations, using the data as a framework for the field work. Once the basic habitats and broad wildlife effects have been determined, the biologist will need to refine the analysis based on such things as interspersion of habitat types, the presence or absence of special habitats, specific requirements of species for water, space, and cover, and a host of other factors beyond broad habitat needs that enter into determining habitat suitability for a particular species.

The data are especially applicable in land management planning, compartment planning[1], and most project planning. It is important, however, to understand the *limits of resolution* of the data base. Larger areas tend to include more of the special habitat requirements of species, to have a greater variety and interspersion of habitat types and seral stages, and to include larger blocks of the various habitats. Consequently, the larger the area analyzed the more accurate will be the predictions of project impacts on habitats, while the smaller (or more site specific) the area is, the less accurate will be the predictions. Thus, the smaller the project site, the greater is the need for biological expertise in refining the wildlife predictions based on information in this publication.

Application of the data reported in making project assessments can be done at different levels, some simple and easily done by hand. More complex assessments, however, are beyond reach of the paper-and-pencil approach. An example is the assessment of probable effects of a large timber sale, involving vegetation changes in several habitat stages, on all vertebrate species within the sale area. For this reason, all of the basic information contained in this publication has been computerized for greater accessibility.

Even without access to a computer, however, it is still possible to use the information for simple analyses, by following these steps:

First, tailor the information to your particular area of interest—for example, for forest biologists, it could be a National Forest or Ranger District—by identifying all the animal species that do not occur in your management area. Use the distribution maps to determine the species not found in your area, and shade over, with a coloring pen, for example, the full species/habitat matrix entry for each species. You can then ignore shaded entries in future use of the species/habitat matrix. If local observations show that a species regularly occurs in your management area, even though the distribution map does not, consider the distribution map to be in error.

Second, use the information for reference on any species you have a particular question about. If the information supplied is not adequate, consult the references listed for that species.

Third, use the information to compile a list of species likely to be found in any given habitat stage by scanning down the species/habitat matrix under the habitat stage of interest. Each time you find an entry for a species, *check across to the special habitat requirements for that species*. If it has special habitat requirements that are not provided on the project site, do not add it to your list of species. You will see from this step that compiling the species list is *a two-step process of eliminating species not likely to use an area*. Note in the species/habitat matrix, for example, that mallards may be found in any stage of any habitat, but only if a suitable aquatic site is available. Because of the importance of the special habitat requirements in screening out species not likely to utilize a project site, it is important that you visit the project area before compiling the species list. During the visit you should record the occurrence and extent of such features as riparian zones, lakes, ponds, marshes, rock outcrops, cliffs, litter, snags, and other special habitat requirements.

Fourth, and perhaps most important, use the information to get an idea of the species whose populations

likely will be affected, either positively or negatively, by a project. If you know the nature of the change in vegetation to be expected in a given habitat stage, as a result of a project, you may compile "before" and "after" lists of species. At least a simple level of assessment is possible by comparing the two lists.

Any Threatened, Endangered, Rare, or Sensitive animal species likely to be affected by the project should be brought to your attention. This no doubt will require thorough inventory of the project site to learn whether or not the species is actually present. If it is, take steps to learn more about its use of that site, to start (for Threatened or Endangered species) the required consultation process with the Fish and Wildlife Service, U.S. Department of Interior, and to explore possible ways to avoid all negative effects.

Many other ways exist in which animal species lists generated from the species/habitat matrix can be developed to serve the management function. The only constraint is that conclusions should not be drawn that exceed the limits of accuracy of the original data.

Accuracy of Data

This publication should be considered just the beginning in the task of assembling the needed wildlife information to enable comprehensive management of western Sierra Nevada habitats. It is, however, the best single source available for permitting forest managers to assess the effects of habitat modification on wildlife species. Nonetheless, the data base still can be expanded, improved, and made more accurate. For this reason, the California Wildlife Habitat Relationships Program will be involved in the future with testing the data in this and other documents in the series, and in evaluating predictions based on those documents.

Comments and suggestions from users and other readers are welcomed. Address correspondence to:

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Pacific Southwest Region
Forest Service, U.S. Department of Agriculture
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Periodically, as more information accumulates, this publication will be updated or supplemented, and new methods will be developed to evaluate management proposals.

The recognized limitations in the information assembled here call for some caution by users in applying it to management decisions:

- It is not a substitute for professional field work and experience. In particular, it is not a substitute for ground checking each site proposed for a management project. The very nature of the way the information is organized—especially its method of dealing with special habitat requirements—calls for field time of a person informed about how to apply this information.
- The scoring system for designating habitat suitability uses ordinal numbers (1, 2, and 3) for ranking purposes only. These numbers are not intended to indicate that optimum habitat is twice as good as suitable or three times as good as marginal habitat. Therefore, any application of these suitability classes to management problems should be done in a manner consistent with the intended ranking system.
- Only habitat *potentially* suitable for any given species is identified. A list of species potentially using any given habitat stage, for example, a block of mature mixed-conifer forest 100 acres (40 ha) in size, with 80 percent canopy cover, no doubt would include more species than actually could be found on the site. This condition reflects the fact that factors other than just features of a habitat stage have an important influence on a species' occurrence in any given area. *This effect diminishes with increasing size of the sample area.* For example, Marcot[2] found that "potential" lists developed from the North Coastal Zone were three to four times longer than "actual" lists produced by field verification of species occurrence. Marcot's plots, on the Six Rivers National Forest in northern California, were only about 5 acres (2 ha) in size. An analysis at the compartment level, however, should produce a potential list much more closely matching the actual list. In any case, if any analysis using the species/habitat matrix information indicates that the manager should be concerned for a certain species' welfare, *it will be necessary to inventory the area five or more times to determine whether or not that species actually* occurs there.
- The species/habitat matrix does not account for patch size of any given habitat stage, in terms of whether or not it is likely to be used by a species. Obviously small patches of habitat are more likely to be suitable for small animal species, or for species with small territory or home range requirements, than they are for large species with large territories and home ranges. The wildlife biologist will need to study the home range or territory size requirements, or both, or emphasis species guidelines when available, to determine whether patch sizes likely would accommodate a species in question.
- The related question of how many animals of a given species can occupy a patch of known size is also not answered here. A very crude guess might be made by dividing patch size by average territory or home range size, but we do not recommend this procedure. Typically, not all parts of a given patch will be equally suitable for use by the animal species, so not all the patch will be

occupied. As a result, dividing patch size by territory or home range size will overestimate animal density by an unknown amount. Until much more is known about these relationships, so that specific guidelines may be established for relating home range size to estimates of population numbers, the safest procedure for estimating population size is to undertake an accepted field counting procedure. In practice, it is likely that for most projects a knowledge of actual population size will be necessary only for a limited number of species.

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[1] A land area delineated by the Forest Service, U.S. Department of Agriculture, for resource record-keeping. Compartments in the Pacific Southwest Region generally range in size from 3,000 to 12,000 acres.

[2] Personal communication from Bruce Marcot, Six Rivers National Forest, Eureka, Calif., March 1979.

Amphibians and Reptiles

Harold E. Basey and *David A. Sinclear*

This chapter offers the most recent information available on the habitat relationships of the 26 species of amphibians and 27 species of reptiles known to occur on the west slope of the Sierra Nevada. Nomenclature used follows that in the most recent literature for each species. The species are arranged in phylogenetic order and numbered in sequence, with prefix "A" (amphibians) or "R" (reptiles), for purposes of internal cross-referencing and computer access coding.

In addition to the literature cited for the various species treated in this chapter, several general sources will be invaluable to the forest manager in assessing the effects of forest management on amphibians and reptiles. The sources include Van Denburg (1922), Grinnell and Storer (1924), Storer (1925), Grinnell *et al.* (1930), Adams (1942), Smith (1946), Bishop (1947), Wright and Wright (1949, 1957), and Wake (1974).

The species notes identify numerous areas in which our knowledge of the biology of amphibians and reptiles is inadequate to permit wise management decisions. To this extent, this publication will serve as a useful guide to researchers and others interested in pursuing field work on the species covered here.

Species List

A001 Tiger Salamander
Ambystoma tigrinum

A002 Long-toed Salamander
Ambystoma macrodactylum

A003 California Newt
Taricha torosa

A004 Rough-skinned Newt
Taricha granulosa

A005 Pacific Giant Salamander
Dicamptodon ensatus

A006 Mount Lyell Salamander
Hydromantes platycephalus

A007 Limestone Salamander
Hydromantes brunus

A008 Shasta Salamander
Hydromantes shastae

A009 Ensatina
Ensatina eschscholtzi

A010 California Slender Salamander
Batrachoseps attenuatus

A011 Relictual Slender Salamander
Batrachoseps relictus

A012 Kern Canyon Slender Salamander
Batrachoseps simatus

A013 Tehachapi Slender Salamander
Batrachoseps stebbinsi

A014 Arboreal Salamander
Aneides lugubris

A015 Black Salamander
Aneides flavipunctatus

A016 Tailed Frog
Ascaphus truei

A017 Western Spadefoot
Scaphiopus hammondii

A018 Western Toad
Bufo boreas

A019 Yosemite Toad
Bufo canorus

A020 Pacific Treefrog
Hyla regilla

A021 Red-legged Frog
Rana aurora

A022 Cascades Frog
Rana cascadae

A023 Leopard Frog
Rana pipiens

A024 Foothill Yellow-legged Frog
Rana boylei

A025 Mountain Yellow-legged Frog
Rana muscosa

A026 Bullfrog
Rana catesbeiana

R001 Western Pond Turtle
Clemmys marmorata

R002 Western Fence Lizard
Sceloporus occidentalis

R003 Sagebrush Lizard
Sceloporus graciosus

R004 Side-blotched Lizard
Uta stansburiana

R005 Coast Horned Lizard
Phrynosoma coronatum

R006 Gilbert's Skink
Eumeces gilberti

R007 Western Skink
Eumeces skiltonianus

R008 Western Whiptail
Cnemidophorus tigris

R009 Southern Alligator Lizard
Gerrhonotus multicarinatus

R010 Northern Alligator Lizard
Gerrhonotus coeruleus

R011 California Legless Lizard
Anniella pulchra

R012 Rubber Boa
Charina bottae

R013 Ringneck Snake
Diadophis punctatus

R014 Sharp-tailed Snake
Contia tenuis

R015 Racer
Coluber constrictor

R016 Coachwhip
Masticophis flagellum

R017 Striped Racer
Masticophis lateralis

R018 Gopher Snake
Pituophis melanoleucus

R019 Common Kingsnake
Lampropeltis getulus

R020 California Mountain Kingsnake
Lampropeltis zonata

R021 Long-nosed Snake
Rhinocheilus lecontei

R022 Common Garter Snake
Thamnophis sirtalis

R023 Western Terrestrial Garter Snake
Thamnophis elegans

R024 Western Aquatic Garter Snake
Thamnophis couchi

R025 Western Black-headed Snake
Tantilla planiceps

R026 Night Snake
Hypsiglena torquata

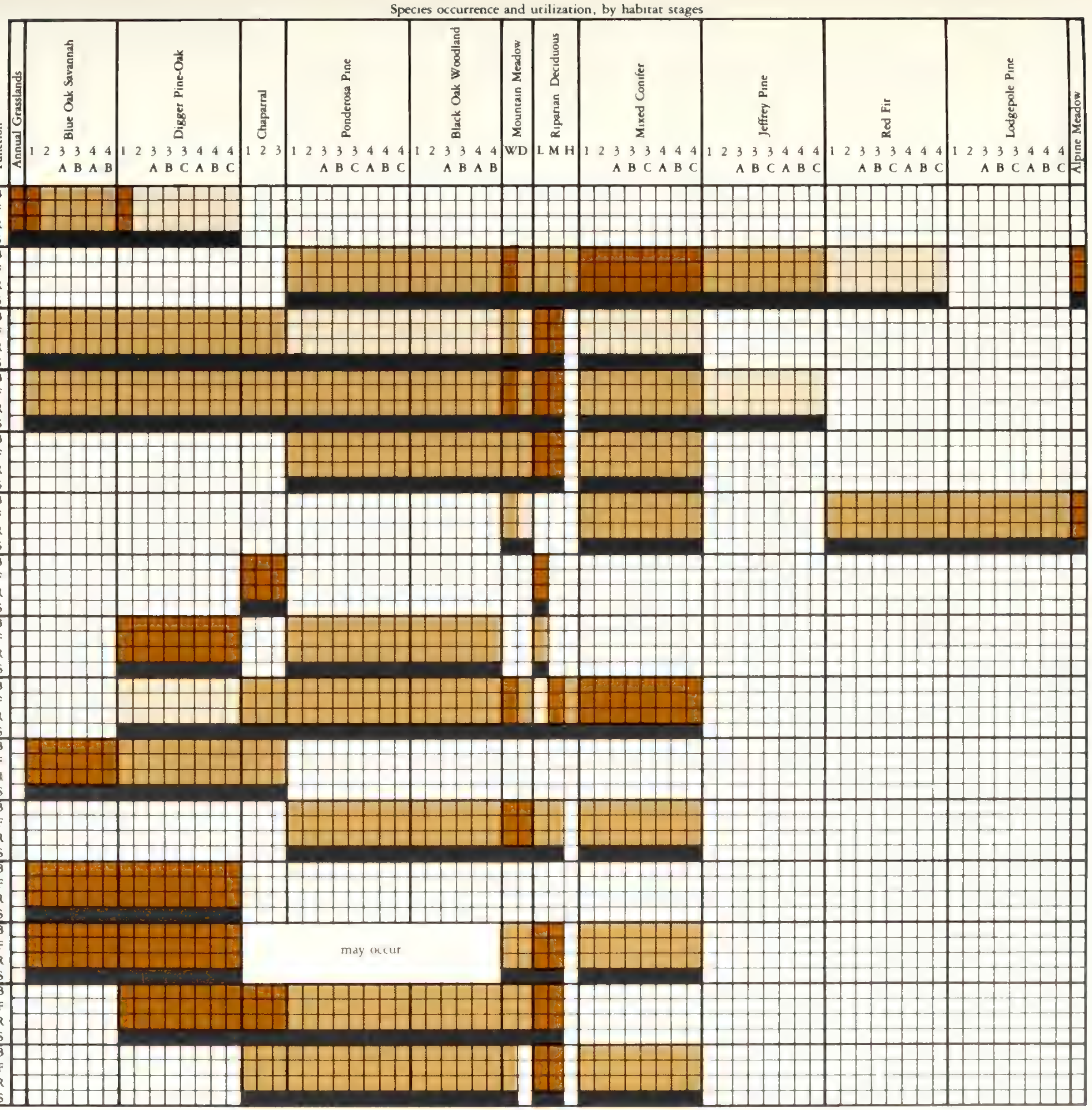
R027 Western Rattlesnake
Crotalus viridis

LEGEND

- Optimum Habitat (1)
- Suitable Habitat (2)
- Marginal Habitat (3)
- Spring
- Summer
- Fall
- Winter

For key to this matrix, see *figure 2*.

Code	Species	Special Habitat Requirements	Page	Function
A001	Tiger Salamander	Ponds; ground burrows	19	B F R S
A002	Long-toed Salamander	Ponds, lakes; logs, litter	20	B F R S
A003	California Newt	Ponds, lakes, streams	21	B F R S
A004	Rough-skinned Newt	Ponds, lakes, streams	22	B F R S
A005	Pacific Giant Salamander	Permanent streams	23	B F R S
A006	Mount Lyell Salamander	Talus; springs, seeps	24	B F R S
A007	Limestone Salamander **RARE**	Limestone outcrops	25	B F R S
A008	Shasta Salamander **RARE**	Limestone outcrops	26	B F R S
A009	Ensatina	Moist soil, logs, litter	27	B F R S
A010	California Slender Salamander	Moist soil, logs, litter	28	B F R S
A011	Relictual Slender Salamander	Moist soil, springs, seeps	29	B F R S
A012	Kern Canyon Slender Salamander **RARE**	Moist soil; logs, litter	30	B F R S
A013	Tehachapi Slender Salamander **RARE**	Moist soil, logs, litter	31	B F R S
A014	Arboreal Salamander	Ground burrows, moist soil, litter	32	B F R S
A015	Black Salamander		33	B F R S

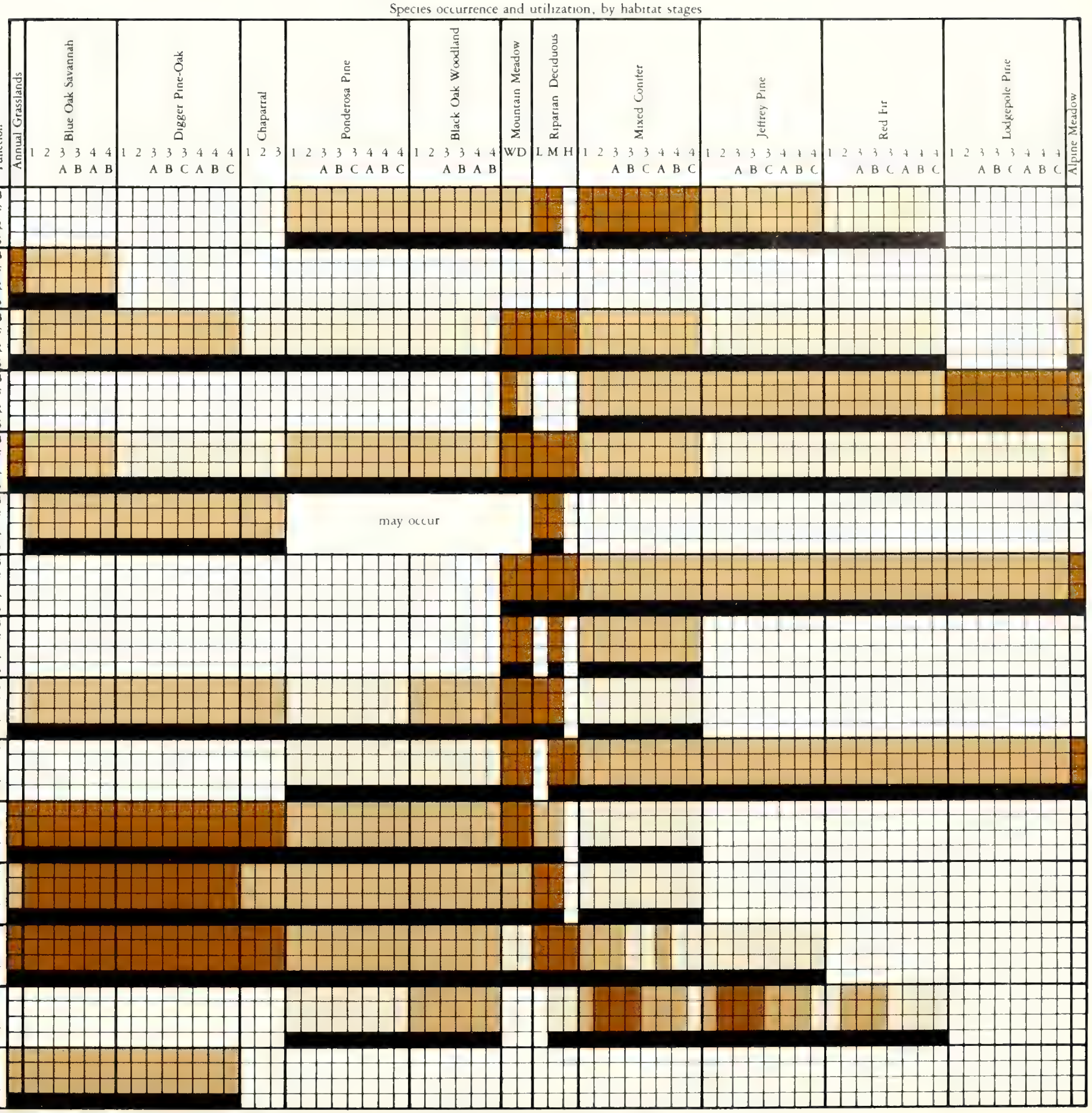


LEGEND
- Optimum Habitat (1)
- Suitable Habitat (2)
- Marginal Habitat (3)
- Spring
- Summer
- Fall
- Winter

For key to this matrix, see *figure 2*

Code	Species	Special Habitat Requirements	Page	Function
A016	Tailed Frog	Permanent streams	34	B F R S
A017	Western Spadefoot	Ponds	35	B F R S
A018	Western Toad	Water, ponds	36	B F R S
A019	Yosemite Toad	Water; ponds	37	B F R S
A020	Pacific Treefrog	Water	38	B F R S
A021	Red-legged Frog	Permanent streams	39	B F R S
A022	Cascades Frog	Ponds, streams	40	B F R S
A023	Leopard Frog	Ponds, lakes	41	B F R S
A024	Foothill Yellow-legged Frog	Permanent streams	42	B F R S
A025	Mountain Yellow-legged Frog	Permanent streams, ponds, lakes	43	B F R S
A026	Bullfrog	Water; ponds, pools, lakes, streams	44	B F R S
R001	Western Pond Turtle	Permanent streams, lakes	45	B F R S
R002	Western Fence Lizard	Rock outcrops, friable soil	46	B F R S
R003	Sagebrush Lizard	Rock outcrops, friable soil	47	B F R S
R004	Side-blotched Lizard	Friable soil	48	B F R S

Species occurrence and utilization, by habitat stages



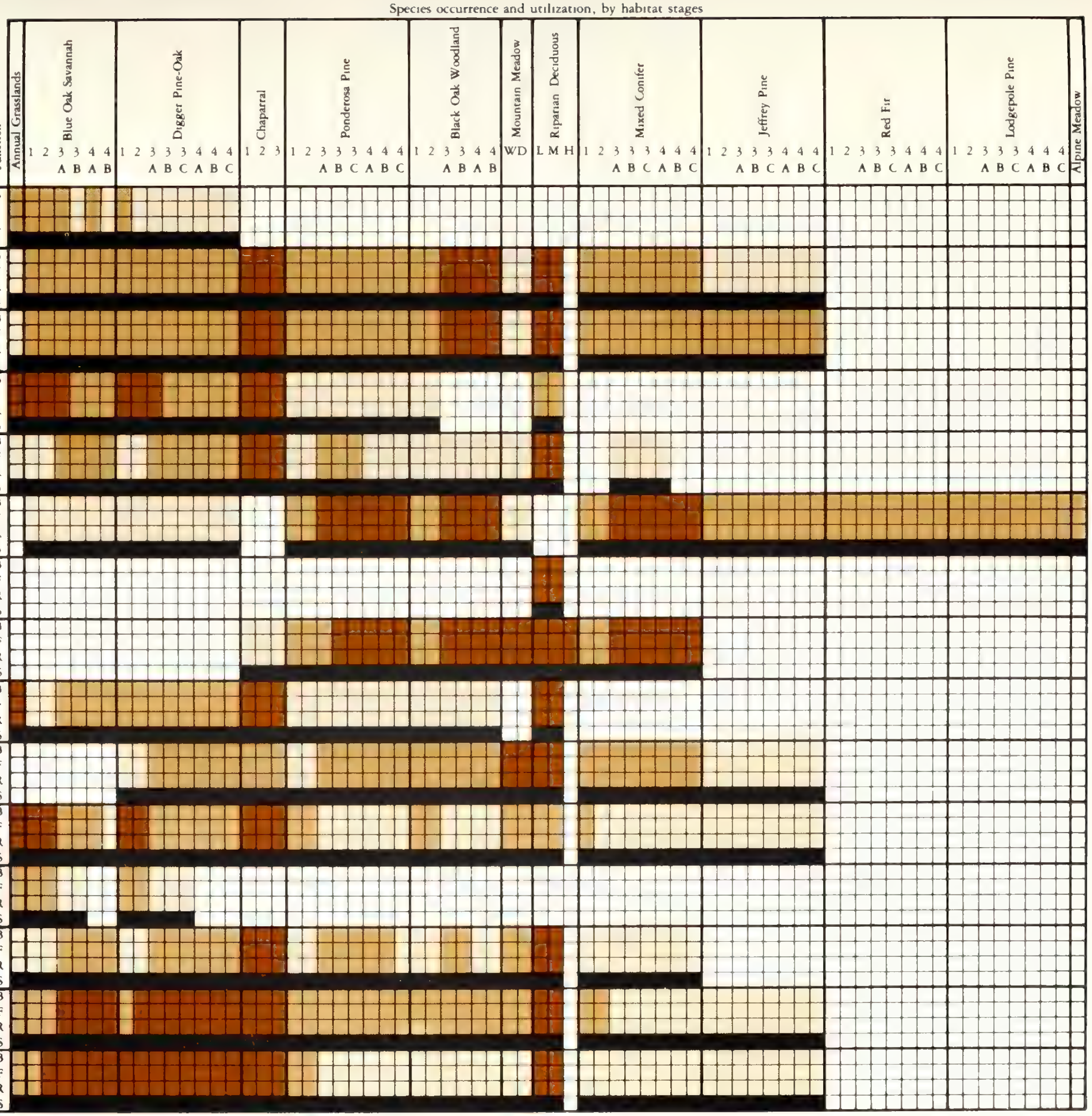
LEGEND

- Optimum Habitat (1)
- Suitable Habitat (2)
- Marginal Habitat (3)
- Spring
- Summer
- Fall
- Winter

For key to this matrix, see *figure 2*.

Species occurrence and utilization, by habitat stages

Code	Species	Special Habitat Requirements	Page	Function
R005	Coast Horned Lizard	Friable soil	49	B F R S
R006	Gilbert's Skink		50	B F R S
R007	Western Skink		51	B F R S
R008	Western Whiptail		52	B F R S
R009	Southern Alligator Lizard		53	B F R S
R010	Northern Alligator Lizard		54	B F R S
R011	California Legless Lizard	Sand	55	B F R S
R012	Rubber Boa		56	B F R S
R013	Ringneck Snake	Moist soil	57	B F R S
R014	Sharp-tailed Snake	Litter	58	B F R S
R015	Racer		59	B F R S
R016	Coachwhip		60	B F R S
R017	Striped Racer		61	B F R S
R018	Gopher Snake		62	B F R S
R019	Common Kingsnake		63	B F R S



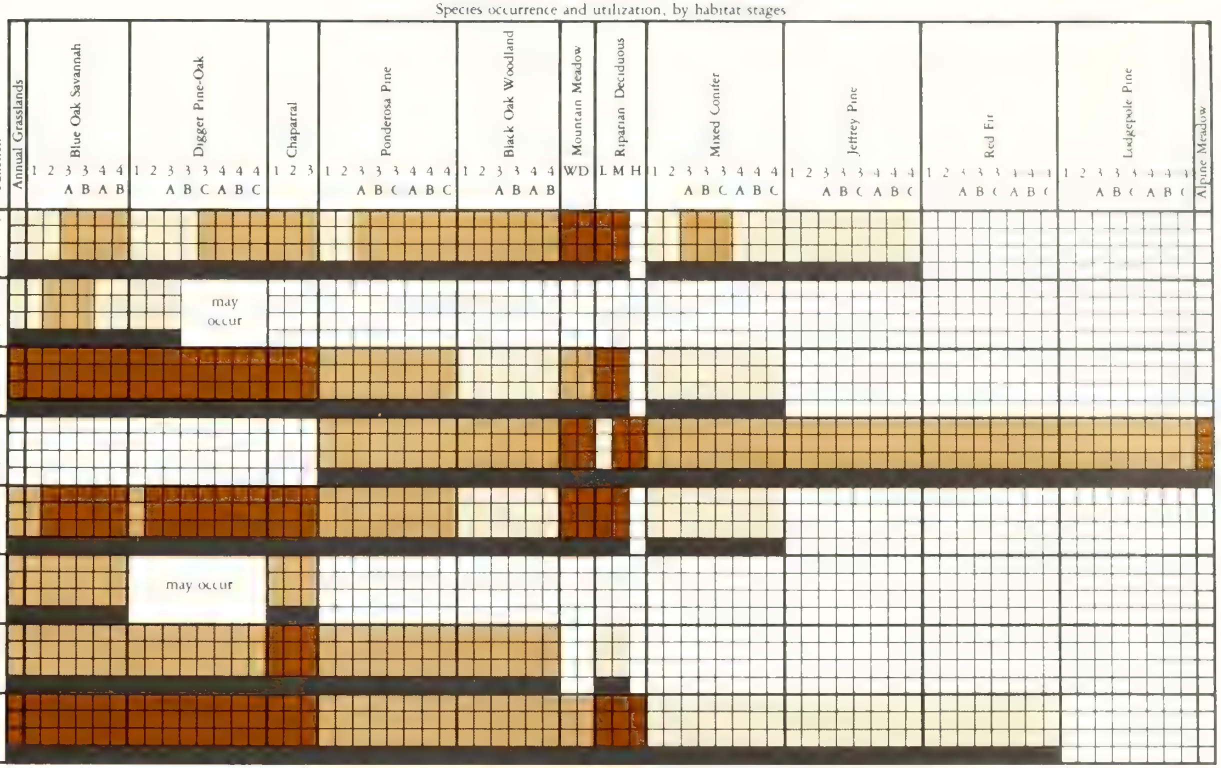
LEGEND

- Optimum Habitat (1)
- Suitable Habitat (2)
- Marginal Habitat (3)
- Spring
- Summer
- Fall
- Winter

For key to this matrix, see *figure 2*

Code	Species	Special Habitat Requirements	Page	Function
R020	California Mountain Kingsnake		64	B F R S
R021	Long-nosed Snake		65	B F R S
R022	Common Garter Snake		66	B F R S
R023	Western Terrestrial Garter Snake	Permanent streams, ponds, lakes	67	B F R S
R024	Western Aquatic Garter Snake	Permanent streams, ponds	68	B F R S
R025	Western Black-headed Snake		69	B F R S
R026	Night Snake	Rock outcrops, crevices	70	B F R S
R027	Western Rattlesnake	Rock outcrops	71	B F R S

Species occurrence and utilization, by habitat stages



Tiger Salamander

A001 *(Ambystoma tigrinum)*

STATUS: No official listed status. Considered fragile because conversions of grassland to other types and use of poisons in ponds could have deleterious effects on species.

DISTRIBUTION/HABITAT: Found primarily in grasslands at elevations below 1000 ft (305 m), but has been sighted in an oak woodland habitat on the San Joaquin Experimental Range, Madera County.

SPECIAL HABITAT REQUIREMENTS: Ponds for breeding and ground burrows for summer dormancy.

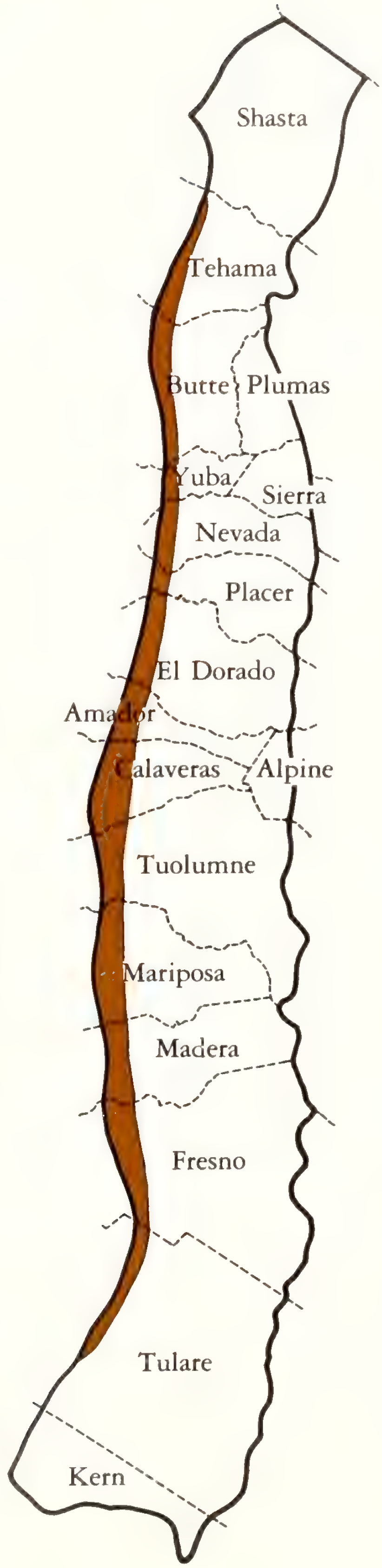
BREEDING: Breeds from December to February in streams, ponds, reservoirs, and wells. Peak breeding varies with rain patterns from year to year. Females lay as many as 500 eggs attached singly or in clumps to submerged objects; many clutches. Mean clutch size 3 to 4 (range 1 to 15).

TERRITORY/HOME RANGE: Not territorial. Home range estimated as 1 acre (0.4 ha); species found up to 600 ft (180 m) from breeding sites.

FOOD HABITS: Aquatic and terrestrial insects and other invertebrates stalked or searched for in ponds, on land surfaces, and under objects.

OTHER:

REFERENCES: Stebbins 1951, 1954a, 1966, 1972; Gehlbach 1967.



Long-toed Salamander

A002 (*Ambystoma macrodactylum*)

STATUS: No official listed status. Common in preferred habitat.

DISTRIBUTION/HABITAT: Found from Stanislaus River drainage northward, with an elevational range of 1000 to 9000 ft (305 to 2740 m). Observed in all successional stages of ponderosa pine type to red fir type with mountain meadow and mixed-conifer types as favored habitats. Permanent bodies of water required at 7400 ft (2265 m), but temporary ponds suffice at 6000 ft (1830 m).

SPECIAL HABITAT REQUIREMENTS: Ponds and lakes for breeding; surface objects, such as logs, around breeding sites.

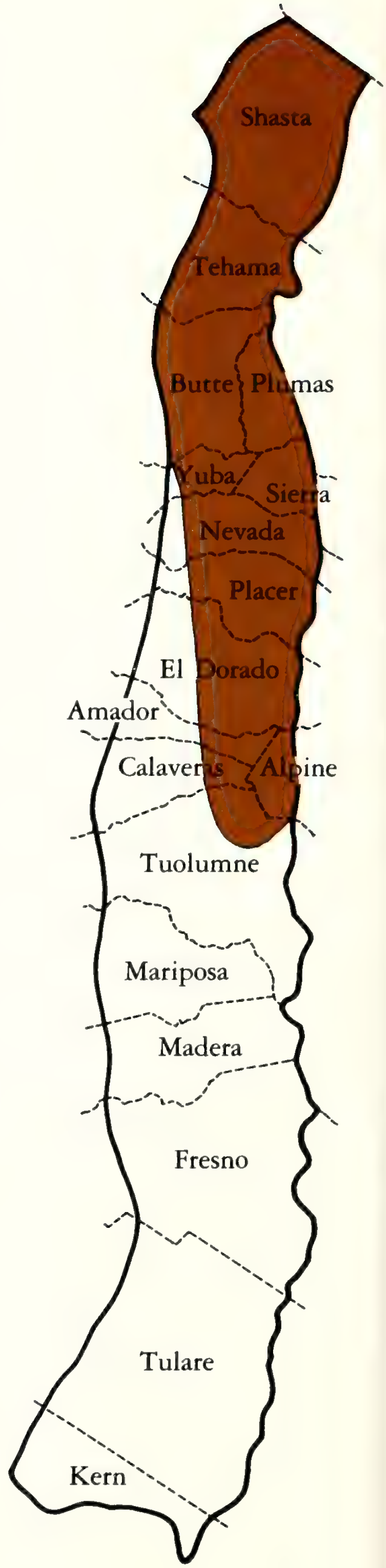
BREEDING: Breeds in May and June, with peak breeding depending on snowmelt. Eggs laid singly (range 85 to 345). Reproduces in small to large bodies of water where eggs are attached to submerged logs or other objects.

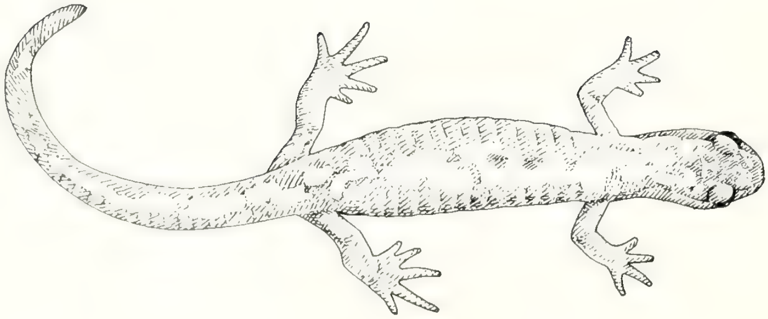
TERRITORY/HOME RANGE: Not territorial. Home ranges estimated up to 1 acre (0.4 ha).

FOOD HABITS: Stalks or scavenges for spiders, insects or insect parts under forest surface objects and in ponds.

OTHER:

REFERENCES: Stebbins 1951, 1954a, 1972; Ferguson 1961, 1963; Anderson 1967.





California Newt

A003 *(Taricha torosa)*

STATUS: No official listed status. Common in preferred habitat.

DISTRIBUTION/HABITAT: Found in all successional stages from blue oak savannah to mixed-conifer types; prefers riparian deciduous. Elevation range up to 6000 ft (1830 m).

SPECIAL HABITAT REQUIREMENTS: Ponds, lakes, and streams.

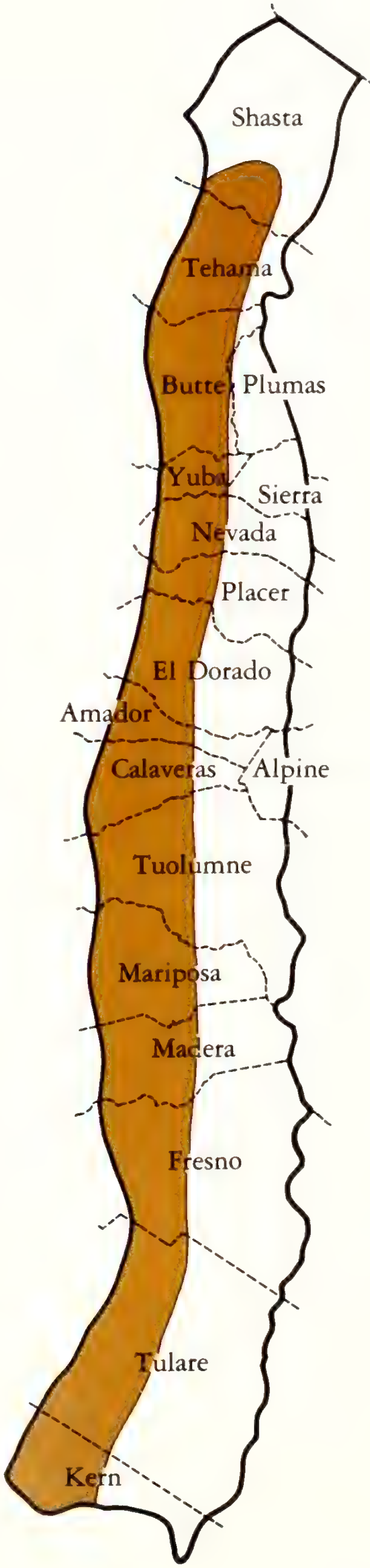
BREEDING: Breeds from February to June, with peak in March and April. Eggs laid in clumps (mean 16, range 6 to 30). Clumps attached to submerged vegetation and underside of boulders. Pools in streams (some lakes and reservoirs) are required breeding sites.

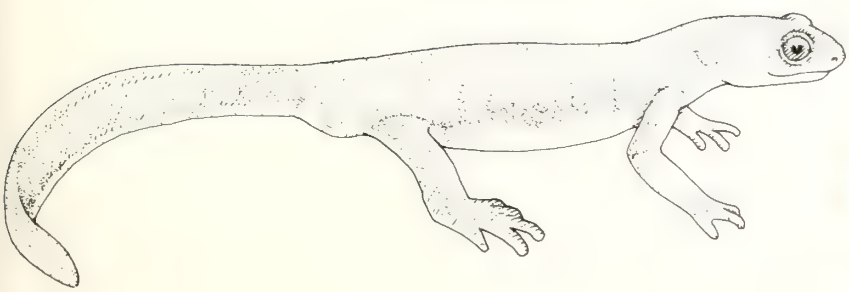
TERRITORY/HOME RANGE: Not thought to be territorial. Home ranges estimated at 1 acre (0.4 ha). Movement to and from breeding sites not included in home range.

FOOD HABITS: Searches for insects under surface objects and in streams.

OTHER: Inactive during late summer and early fall (until it rains). Evidently estivates in burrows and crevices; only a few found at this time of year.

REFERENCES: Stebbins 1951, 1954a, 1972.





Rough-skinned Newt

A004 *(Taricha granulosa)*

STATUS: No official listed status. Common in preferred habitat.

DISTRIBUTION/HABITAT: Found from blue oak savannah to Jeffrey pine types in all successional stages; prefers mountain meadows and riparian deciduous types. Elevation range up to 5000 ft (1520 m). Distribution from east of Chico, Butte County, northward.

SPECIAL HABITAT REQUIREMENTS: Ponds, lakes, and streams for breeding.

BREEDING: Breeds from January to June, with peak activity in March and April. Females found with 1 to 40 eggs; eggs deposited singly.

TERRITORY/HOME RANGE: Not thought to be territorial. Home range estimated to be 1 acre (0.4 ha).

FOOD HABITS: Searches under surface objects and in ponds for insects and other arthropods (primarily aquatic).

OTHER: Inactive during late summer and early fall. Evidently estivates in burrows and crevices; only a few found at this time of year.

REFERENCES: Stebbins 1951, 1954a, 1972.

Pacific Giant Salamander

A005 *(Dicamptodon ensatus)*

STATUS: No official listed status. Common in preferred habitat.

DISTRIBUTION/HABITAT: Found up to 6000 ft (1830 m) in all successional stages of ponderosa pine, black oak woodland, mountain meadow, and mixed-conifer types; prefers riparian deciduous. Lives in damp forests in or near clear streams and rocky shores of mountain lakes in the area of Shasta County, but not in the Sierra Nevada.

SPECIAL HABITAT REQUIREMENTS: Permanent streams for feeding and breeding.

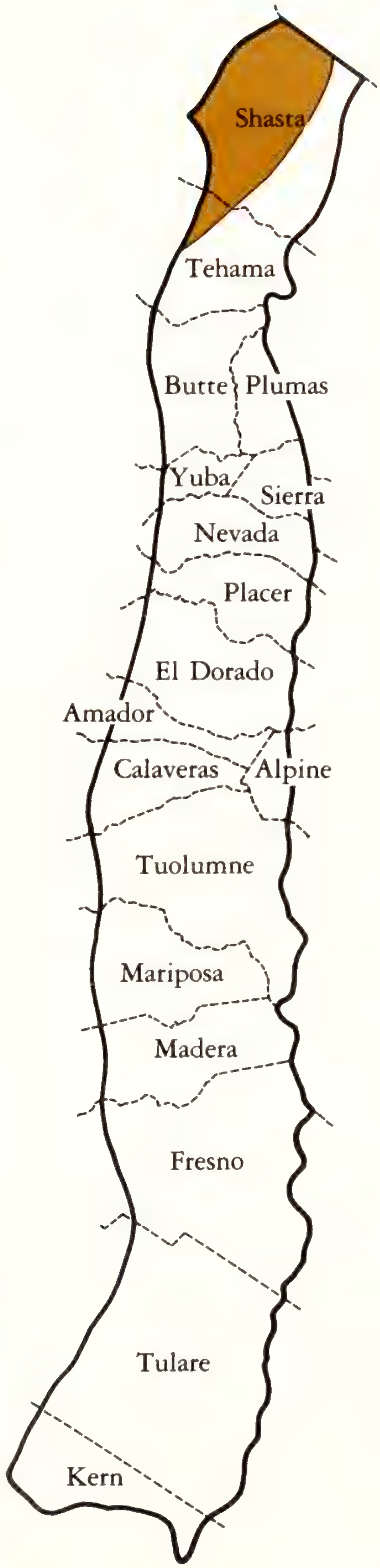
BREEDING: Breeds from March to May, with peak breeding in early May. Eggs laid in concealed locations several feet beneath the surface in cold, slowly flowing water of springs, channels, under streambanks, and beneath rocks in stream bottoms. Mean clutch size unknown but suspected to be 100 (range 70 to 146).

TERRITORY/HOME RANGE: Not thought to be territorial. Home range unknown.

FOOD HABITS: Searches under logs and other surface objects for insects, snails and slugs, shrews, mice and other amphibians.

OTHER:

REFERENCES: Stebbins 1951, 1954a, 1966, 1972; Anderson 1969.



Mount Lyell Salamander

A006 *(Hydromantes platycephalus)*

STATUS: No official listed status. Fragile species; total population relatively small, composed of scattered local populations.

DISTRIBUTION/HABITAT: Wet spots in the high Sierra Nevada—edges of snowbanks, seeps, wet meadows. Found in all successional stages of mixed conifer, red fir, and lodgepole pine. Elevation range 4000 to 11,600 ft (1220 to 3540 m).

SPECIAL HABITAT REQUIREMENTS: Wet areas (springs and seeps), under large granite slabs and boulders at the base of talus slopes.

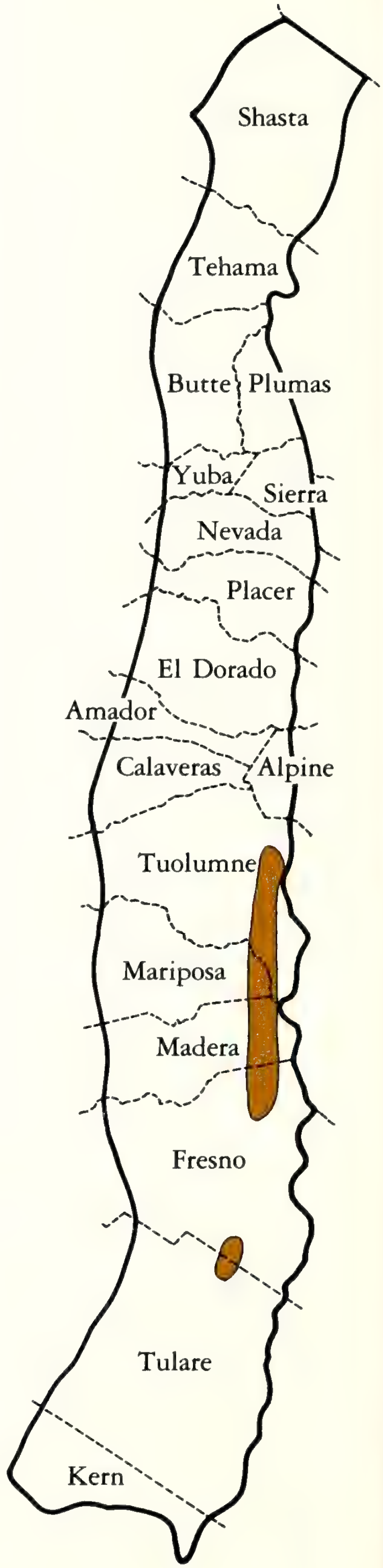
BREEDING: Breeding season unknown. Peak thought to be May and June depending on year. Clutch size unknown; nest site unknown.

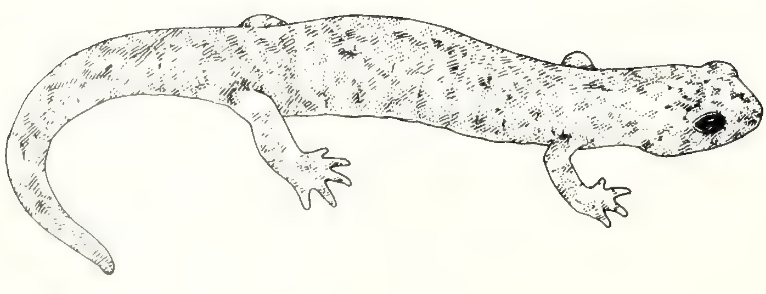
TERRITORY/HOME RANGE: Not thought to be territorial. Home range may be up to 1 acre (0.4 ha), probably less.

FOOD HABITS: Searches for insects and spiders under surface objects.

OTHER: Thought to be a relict of a once widespread species in past Sierra glacial periods. Recent population reported in Desolation Wilderness, El Dorado County, but not confirmed. Species endemic to the Sierra Nevada.

REFERENCES: Adams 1942, Stebbins 1951, 1954a; Gorman 1964.





Limestone Salamander

A007 *(Hydromantes brunus)*

STATUS: Rare (State of California).

DISTRIBUTION/HABITAT: Very limited distribution. Found only along riparian deciduous zone in Merced River Canyon, Mariposa County. Elevation range 840 to 2500 ft (255 to 760 m). Associated with limestone outcrops.

SPECIAL HABITAT REQUIREMENTS: Moist limestone outcrops and caverns.

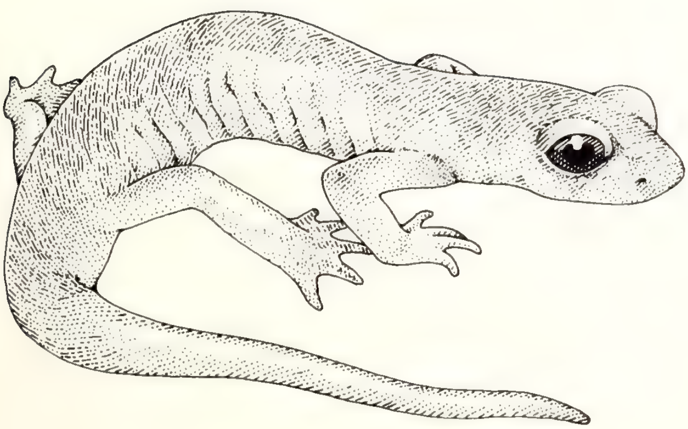
BREEDING: Little definite information. Suspected that it breeds in limestone caverns from May to July, with peak in June. Mean clutch size 7 (range 5 to 14).

TERRITORY/HOME RANGE: Not thought to be territorial. Home range may be as large as 1 acre (0.4 ha).

FOOD HABITS: Searches for insects and other invertebrates under surface objects and in caverns.

OTHER:

REFERENCES: Gorman 1964, Leach *et al.* 1976.



Shasta Salamander

A008 *(Hydromantes shastae)*

STATUS: Rare (State of California).

DISTRIBUTION/HABITAT: Restricted in distribution to limestone outcrops in Lake Shasta area, Shasta County. Found in all successional stages of digger pine-oak, ponderosa pine, and black oak types. Elevation range up to 2500 ft (760 m).

SPECIAL HABITAT REQUIREMENTS: Moist limestone outcrops and caverns.

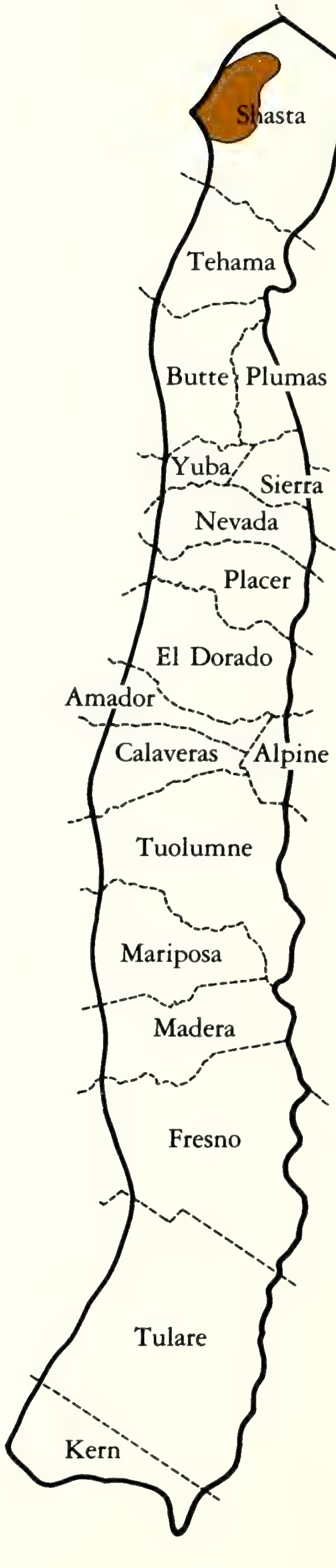
BREEDING: Probably breeds from May to July, with peak breeding in June. Mean clutch size 7 (range 5 to 12). Thought that it breeds in moist limestone caverns.

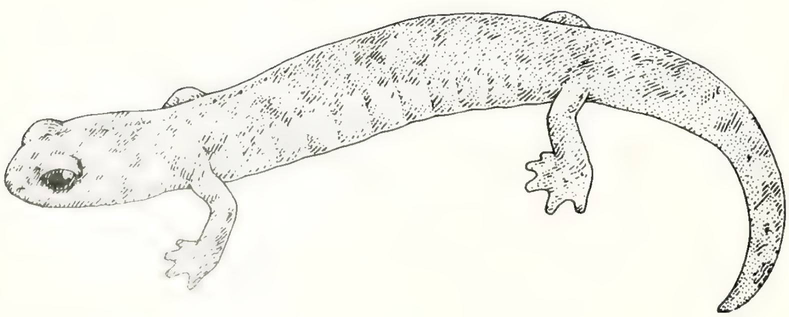
TERRITORY/HOME RANGE: Not thought to be territorial. Home range may be up to 1 acre (0.4 ha).

FOOD HABITS: Searches for insects and other invertebrates under surface objects and in caverns.

OTHER:

REFERENCES: Gorman and Camp 1953, Gorman 1964, Leach *et al.* 1976, Papenfuss and Carufel 1977.





Ensatina

A009 *(Ensatina eschscholtzi)*

STATUS: No official listed status. Common in preferred habitat.

DISTRIBUTION/HABITAT: A forest dweller, found in all successional stages from chaparral to mixed-conifer types. Prefers mountain meadow and mixed-conifer types. Elevation range 1900 to 8000 ft (580 to 2440 m). An upper foothill subspecies, *E. e. xanthoptica,* found from Mokelumne River south to Bass Lake, Madera County.

SPECIAL HABITAT REQUIREMENTS: Moist subsurface areas to lay eggs (under logs and litter).

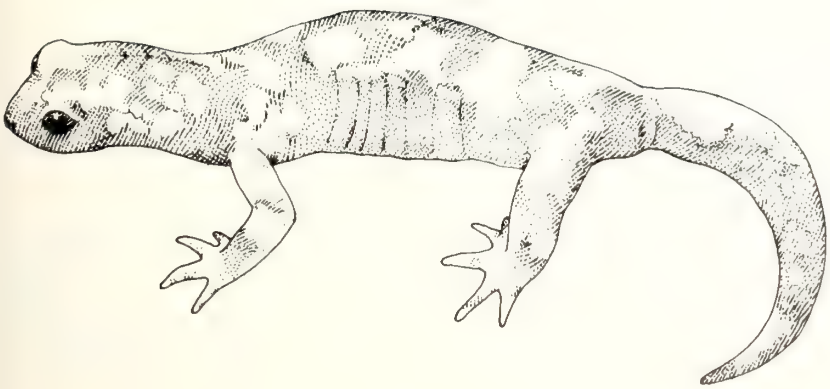
BREEDING: Lays eggs from April to June, with peak activity varying from year to year. Clutch size averages 11 (range 5 to 16).

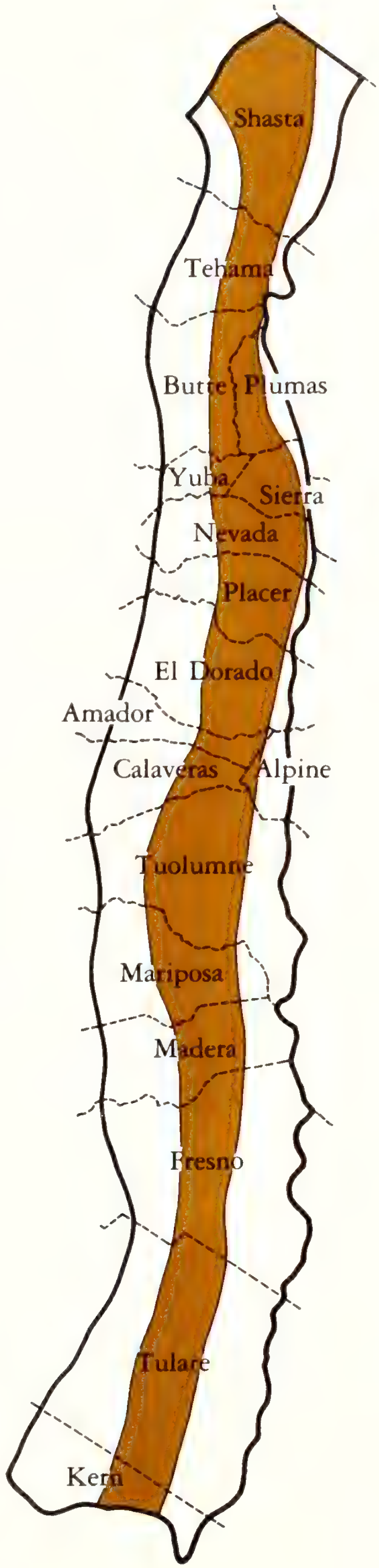
TERRITORY/HOME RANGE: Not thought to be territorial. Home range estimated to be up to 1 acre (0.4 ha).

FOOD HABITS: Searches for insects and other invertebrates under surface objects.

OTHER:

REFERENCES: Stebbins 1954a, 1954b; Brown 1974.





California Slender Salamander

A010 *(Batrachoseps attenuatus)*

STATUS: No official listed status. Common in preferred habitat.

DISTRIBUTION/HABITAT: Found in all successional stages of blue oak savannah, digger pine-oak and chaparral types; prefers blue oak savannah. The only slender salamander found in oak woodlands north of Merced River. Elevation range to 5000 ft (1520 m).

SPECIAL HABITAT REQUIREMENTS: Moist soil under logs and litter.

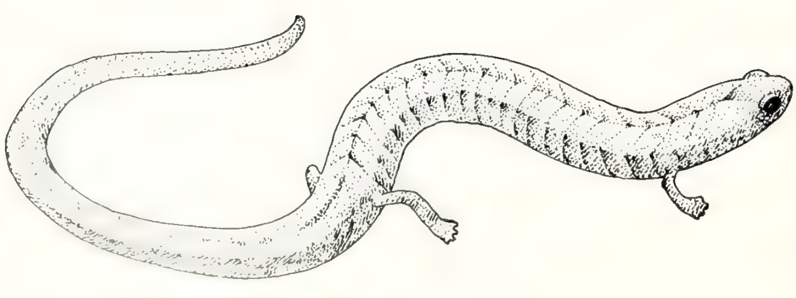
BREEDING: Breeds from October to January, with peak breeding in November. Mean clutch size 9 (range 4 to 25). Eggs laid in moist places under surface objects and in burrows.

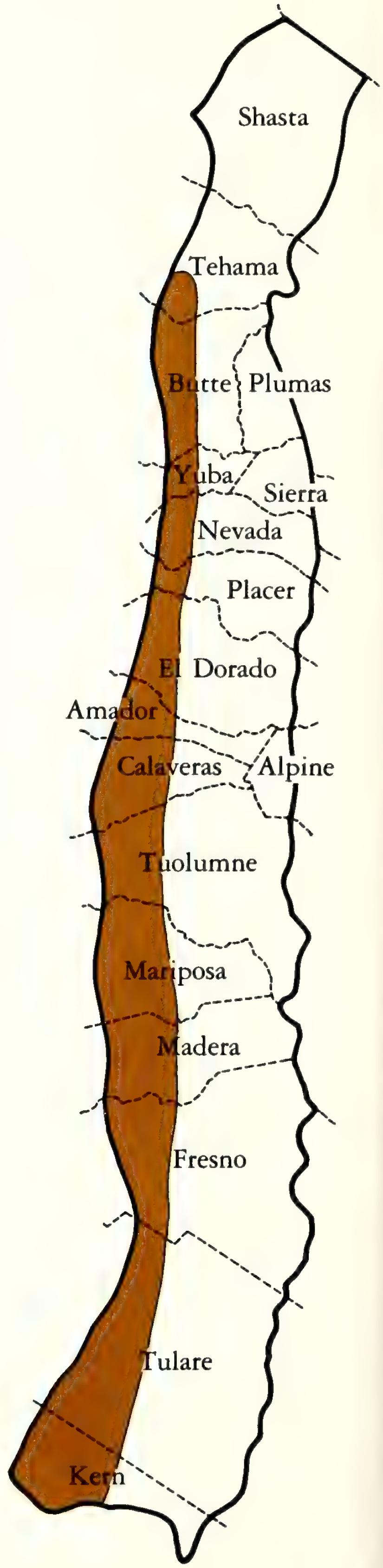
TERRITORY/HOME RANGE: Not thought to be territorial. Home range up to 0.5 acre (0.2 ha).

FOOD HABITS: Searches for small insects and other invertebrates under surface objects.

OTHER:

REFERENCES: Hendrickson 1954, Brame and Murray 1968.





Relictual Slender Salamander

A011 *(Batrachoseps relictus)*

STATUS: No official listed status. Common in preferred habitat.

DISTRIBUTION/HABITAT: Prefers mountain meadows; also found in ponderosa pine, black oak woodland, riparian-deciduous and mixed-conifer types, from Merced River Canyon, Tuolumne County, south. Elevation range up to 8000 ft (2440 m).

SPECIAL HABITAT REQUIREMENTS: Moist soil, springs, and seeps.

BREEDING: Lays eggs in moist places under surface objects from May to July, with peak activity suspected to be in June. Mean clutch size 4 (range 1 to 12).

TERRITORY/HOME RANGE: Not thought to be territorial. Home range suspected to be 0.5 acre (0.2 ha).

FOOD HABITS: Searches for small insects and other invertebrates under surface objects.

OTHER: Species first described in 1968; little ecological information available.

REFERENCES: Stebbins 1966, 1972; Brame and Murray 1968.

Kern Canyon Slender Salamander

A012 *(Batrachoseps simatus)*

STATUS: Rare (State of California).

DISTRIBUTION/HABITAT: Found only in Kern River Canyon, Tulare and Kern Counties. Observed in all successional stages of blue oak savannah; prefers digger pine-oak types. Elevation range 1000 to 4000 ft (305 to 1220 m).

SPECIAL HABITAT REQUIREMENTS: Logs, litter, and moist soil.

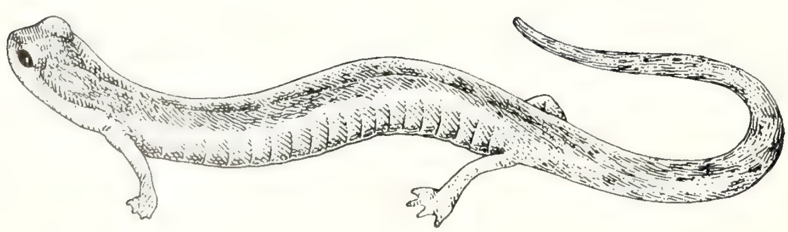
BREEDING: Lays eggs in moist places under surface objects. Clutch size unknown. Suspected to breed from November to February, with peak activity in November.

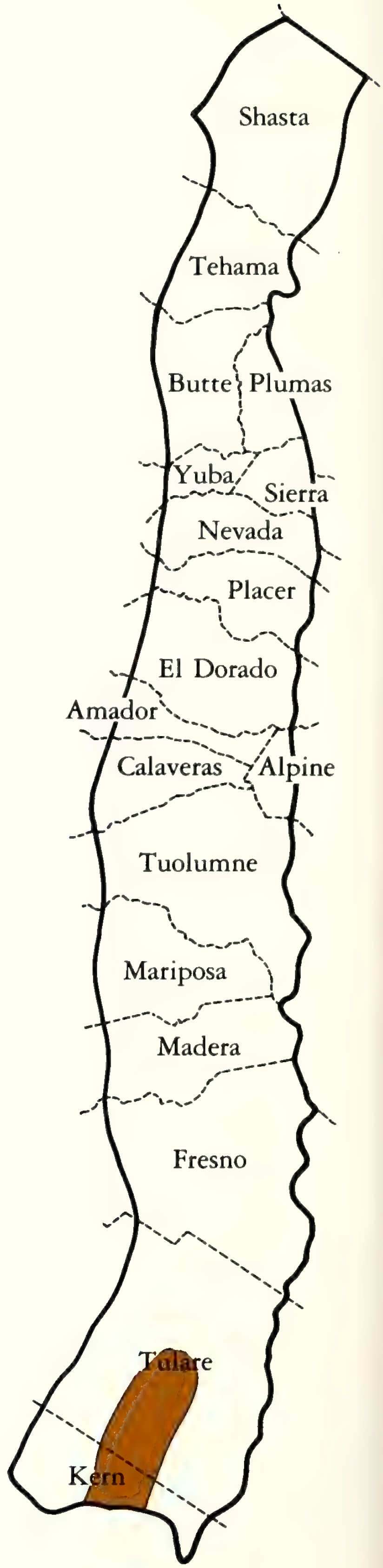
TERRITORY/HOME RANGE: Not thought to be territorial. Home range suspected to be 0.5 acre (0.2 ha).

FOOD HABITS: Forages by searching and waiting for small insects and other invertebrates under surface objects.

OTHER: Species first described in 1968; little ecological information available.

REFERENCES: Brame and Murray 1968, Leach *et al.* 1976.





Tehachapi Slender Salamander

A013 *(Batrachoseps stebbinsi)*

STATUS: Rare (State of California).

DISTRIBUTION/HABITAT: Found only in Tulare and Kern Counties. Reported found from 2500 to 8300 ft (760 to 2530 m). Prefers all successional stages of blue oak savannah, digger pine-oak, and riparian deciduous types. Other habitats are mountain meadow and all successional stages of mixed conifer.

SPECIAL HABITAT REQUIREMENTS: Moist places under logs and litter.

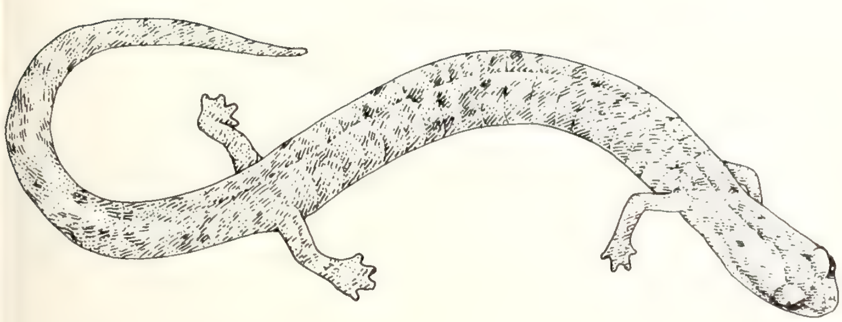
BREEDING: Eggs laid in moist places under surface objects. Breeding season suspected to be from November to February, with peak activity in November and December. Clutch size unknown.

TERRITORY/HOME RANGE: Not thought to be territorial. Home range suspected to be 0.5 acre (0.2 ha).

FOOD HABITS: Searches or waits for small insects and other invertebrates under surface objects.

OTHER: First described in 1968; little ecological information available.

REFERENCES: Brame and Murray 1968, Leach *et al.* 1976.



Arboreal Salamander

A014 *(Aneides lugubris)*

STATUS: No official listed status. Common in preferred habitat.

DISTRIBUTION/HABITAT: Found from 1000 to 5000 ft (305 to 1520 m) from Madera County north to El Dorado County. Prefers digger pine-oak, chaparral, and riparian deciduous types. Also found in ponderosa pine, black oak woodland, and mountain meadow types. Usually found in association with interior live oak.

SPECIAL HABITAT REQUIREMENTS: Moist places under logs and litter. Uses ground burrows during summer.

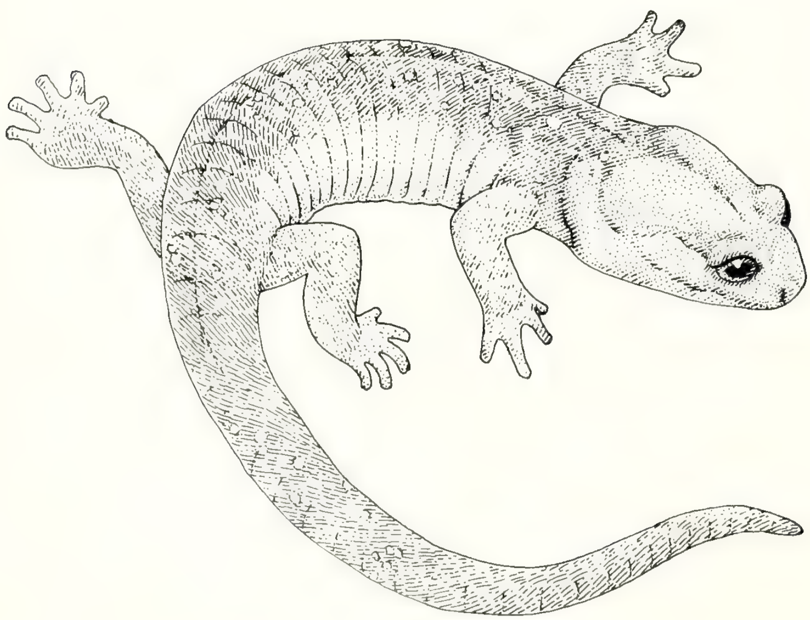
BREEDING: Eggs laid from May to June in moist places under surface objects, in logs, and occasionally up in trees, with peak activity around June 1. Mean clutch size 17 (range 12 to 23).

TERRITORY/HOME RANGE: Not thought to be territorial. Home range suspected to be 1 acre (0.4 ha).

FOOD HABITS: Searches or waits for insects and other invertebrates under surface objects. Also eats some fungi.

OTHER: Primarily a foothill species.

REFERENCES: Stebbins 1951, 1954a, 1966, 1972; Rosenthal 1957, Lynch and Wake 1974.



Black Salamander

A015 *(Aneides flavipunctatus)*

STATUS: No official listed status. Common in its preferred habitat.

DISTRIBUTION/HABITAT: Distributed in Shasta Lake area, Shasta County. Found in all successional stages of digger pine-oak, chaparral, ponderosa pine, black oak woodland, and mixed-conifer types. Also occurs in wet mountain meadows and riparian deciduous types. Elevation range 1000 to 4000 ft (305 to 1220 m).

SPECIAL HABITAT REQUIREMENTS: Unknown.

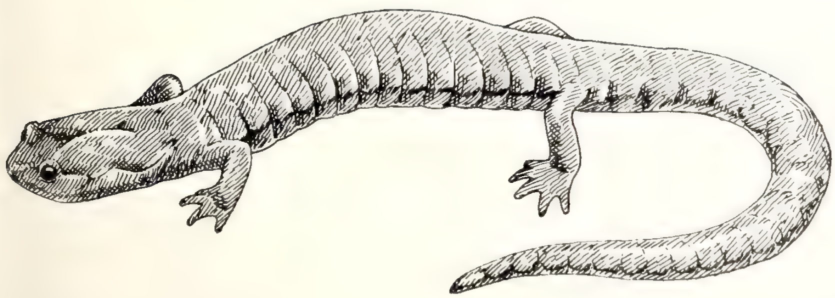
BREEDING: Eggs laid in moist places under surface objects from June to August, with peak activity in July. Mean clutch size 15 (range 5 to 30).

TERRITORY/HOME RANGE: Not thought to be territorial. Suspected home range 1 acre (0.4 ha).

FOOD HABITS: Searches or waits for insects and other invertebrates under surface objects.

OTHER:

REFERENCES: Stebbins 1951, 1954a, 1966, 1972; Lynch 1974.



Tailed Frog

A016 *(Ascaphus truei)*

STATUS: No official listed status. Status needs study.

DISTRIBUTION/HABITAT: Edge of its range in the McCloud River drainage, Shasta County, and not reported in the Sierra Nevada. Found in fast-moving streams from ponderosa pine to red fir type in all successional stages. Prefers riparian deciduous and mixed-conifer types.

SPECIAL HABITAT REQUIREMENTS: Permanent streams for breeding.

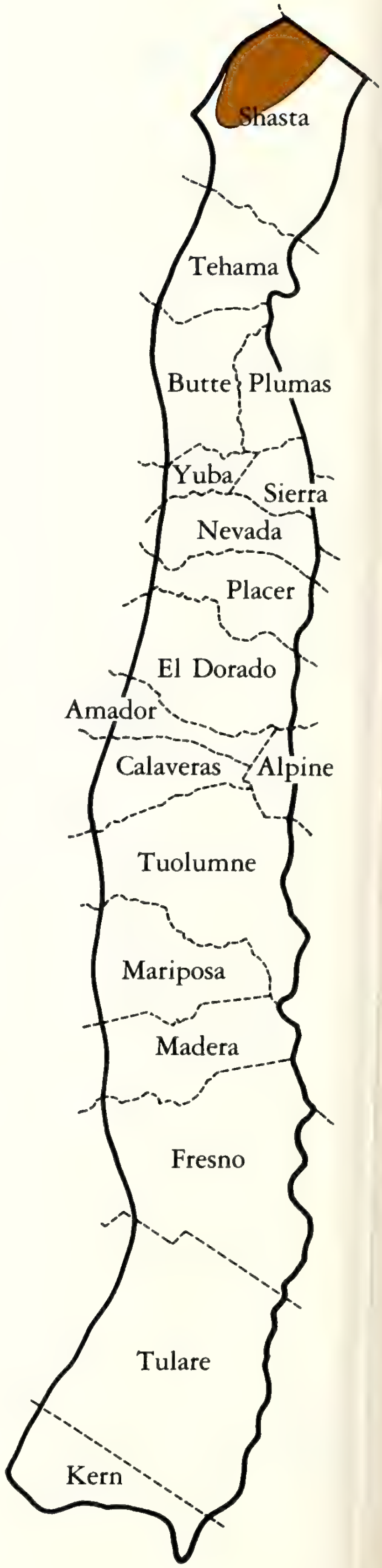
BREEDING: Eggs laid in cool streams in summer; mates in August and September. Mean clutch size 40 (range 35 to 50).

TERRITORY/HOME RANGE: Not territorial. Home range unknown.

FOOD HABITS: Adults wait for prey (insects and other invertebrates) in streams and on wet forest surfaces. Larvae eat algae and pollen.

OTHER:

REFERENCES: Stebbins 1951, 1954a, 1972; Bury 1968, Metter 1968.



Western Spadefoot

A017 *(Scaphiopus hammondii)*

STATUS: No official listed status. Habitat loss because of agricultural conversion.

DISTRIBUTION/HABITAT: Common in grassland at lower elevations. Found above 1000 ft (305 m) in only a few areas, such as the San Joaquin Experimental Range, Madera County.

SPECIAL HABITAT REQUIREMENTS: Winter-spring ponds.

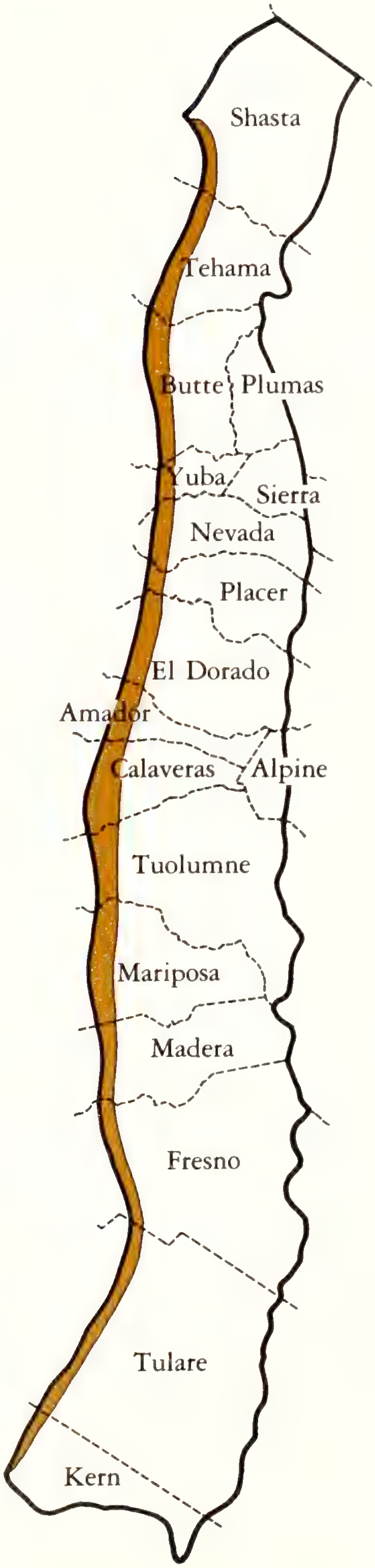
BREEDING: Eggs laid in vernal pools (ponds) and occasionally in slow streams from February to April, with peak activity in March. Mean clutch size 400 (range 300 to 500).

TERRITORY/HOME RANGE: Territory restricted to vicinity of calling male. Home range suspected to be up to 1 acre (0.4 ha).

FOOD HABITS: Waits for insects and other invertebrates on surface of ponds.

OTHER:

REFERENCES: Stebbins 1951, 1954a, 1966, 1972.



Western Toad

A018 *(Bufo boreas)*

STATUS: No official listed status. Common in preferred habitat.

DISTRIBUTION/HABITAT: Elevation range 1000 to 10,000 ft (305 to 3050 m) in mountain meadow and riparian deciduous types at lower elevations. Uncommon at higher elevations.

SPECIAL HABITAT REQUIREMENTS: Ponds, lakes, streams, or rivers for breeding.

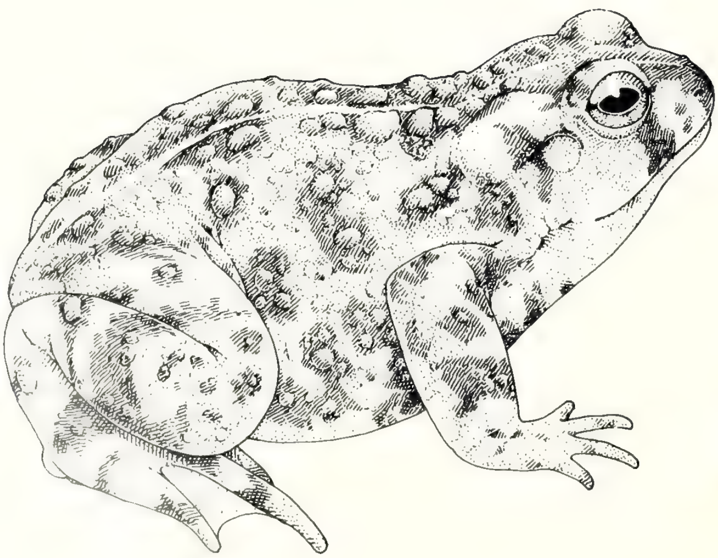
BREEDING: Eggs laid in open water from February to July, with peak activity in April. Peak activity varies with elevation and from year to year. Mean clutch size 10,000 (range 100 to 15,000).

TERRITORY/HOME RANGE: Territory limited to vicinity of calling male. Home range up to 0.5 acre (0.2 ha).

FOOD HABITS: Waits for prey (moving insects) on surface of ground or in shallow burrows.

OTHER: Common toad of California.

REFERENCES: Stebbins 1951, 1954a, 1966, 1972; Karlstrom 1962.



Yosemite Toad

A019 *(Bufo canorus)*

STATUS: No official listed status. Fragile; limited distribution of total species.

DISTRIBUTION/HABITAT: Restricted to central high Sierra Nevada. Prefers mountain meadow, lodgepole pine, and alpine meadow types. Also found in all successional stages of mixed-conifer, Jeffrey pine, and red fir types. Elevation range 6400 to 11,300 ft (1950 to 3440 m).

SPECIAL HABITAT REQUIREMENTS: Relatively warm-water ponds for breeding (usually in meadows).

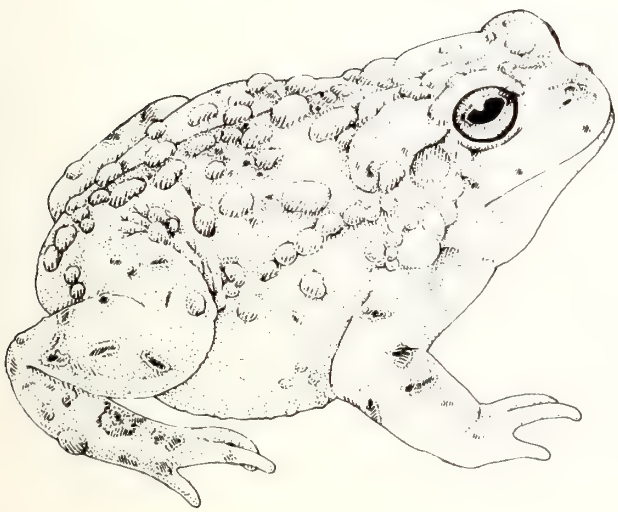
BREEDING: Eggs laid in ponds from April to June, with peak activity in late May (varies from year to year). Karlstrom (1962) indicates they lay "eggs in shallow water where heating effect [of sun] is pronounced." Water temperatures at egg-laying sites range from 45°F to 73° F (7°C to 23°C). Mean clutch size 8000 (range 6000 to 15,000).

TERRITORY/HOME RANGE: Territory restricted to vicinity of calling male. Suspected home range 0.5 acre (0.2 ha).

FOOD HABITS: Waits and pounces on insects and other invertebrates. Forages on the surface of ground.

OTHER: Endemic to the Sierra Nevada.

REFERENCES: Stebbins 1951, 1954a, 1966, 1972; Karlstrom 1962, 1973.



Pacific Treefrog

A020 *(Hyla regilla)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Widespread; found in all habitat types; more common in annual grassland, mountain meadow, and riparian deciduous types. Elevation range to 13,000 ft (3960 m).

SPECIAL HABITAT REQUIREMENTS: Ponds, lakes, streams, or rivers for breeding.

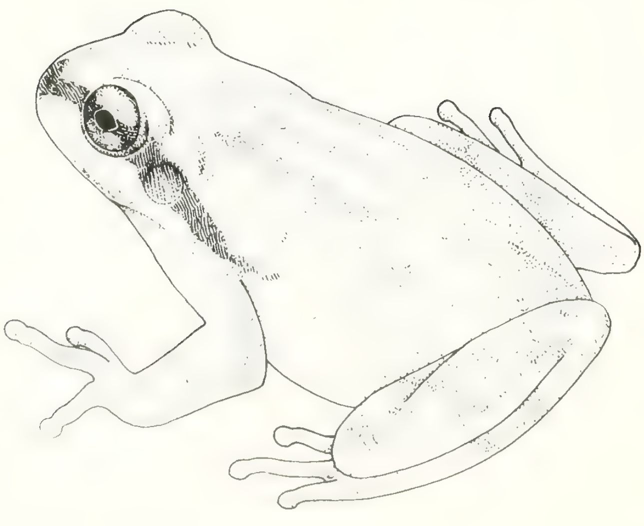
BREEDING: Eggs laid in ponds, lakes, streams, and rivers from February to July. Peak activity from March to June, but varies with elevation and from year to year. Mean clutch size 600 (range 500 to 700).

TERRITORY/HOME RANGE: Territory restricted to vicinity of calling male. Home range unknown.

FOOD HABITS: Waits for and pounces on small insects and other invertebrates in moist areas (meadows and stream edges).

OTHER: A subspecies found in forested areas of the Sierra Nevada; terrestrial and lives away from meadows and streams.

REFERENCES: Stebbins 1951, 1954a, 1966, 1972.



Red-legged Frog

A021 *(Rana aurora)*

STATUS: No official listed status. Fragile. Range recently reduced when Bullfrog introduced. Populations in the central and southern Sierra Nevada rare, perhaps extinct. Detailed study underway.

DISTRIBUTION/HABITAT: Found in blue oak savannah, digger pine-oak, and chaparral habitat types. Prefers riparian deciduous. Primarily found from Mariposa County northward. Elevation range 1000 to 6000 ft (305 to 1830 m). Few present locations known above 1000 ft (305 m).

SPECIAL HABITAT REQUIREMENTS: Quiet pools in permanent streams; pools at least 3 ft (1 m) deep.

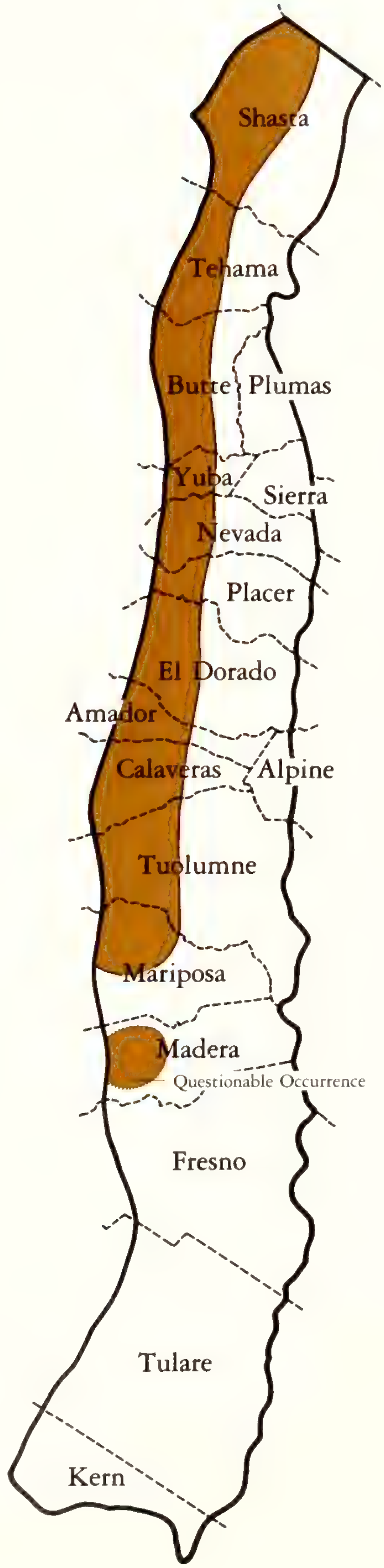
BREEDING: Eggs laid in February and March in pools of permanent, slow-moving streams. Mean clutch size 300 (range 100 to 600).

TERRITORY/HOME RANGE: Not thought to be territorial. Home range unknown.

FOOD HABITS: Waits for and pounces on insects and other small animals near water's edge.

OTHER:

REFERENCES: Stebbins 1951, 1954a, 1966, 1972; Altig and Dumas 1972.



Cascades Frog

A022 (Rana cascadae)

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Limited distribution in the western Sierra Nevada Zone, from northern tip of Butte County northward. Found in forested types—mixed conifer, Jeffrey pine, red fir, and lodgepole pine; prefers mountain meadow, riparian deciduous, and alpine meadow types. Elevation range 1000 to 9000 ft (305 to 2740 m).

SPECIAL HABITAT REQUIREMENTS: Ponds, lakes, streams, or rivers.

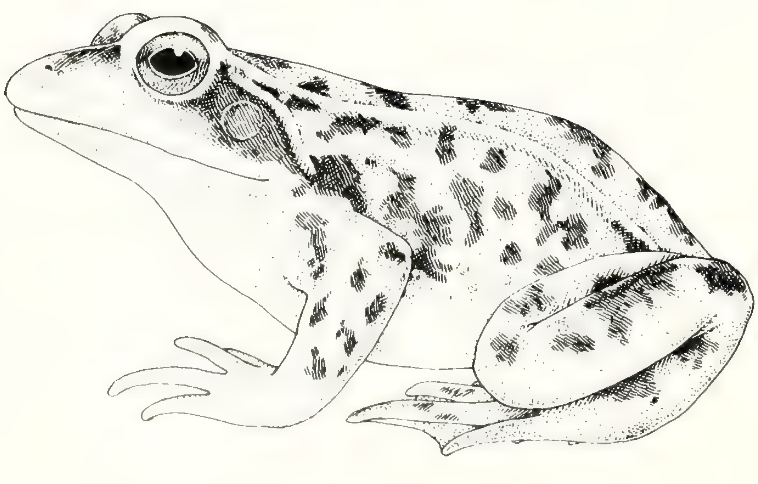
BREEDING: Eggs laid in streams, rivers, ponds, and lakes from March to June, with peak activity in April. Mean clutch size 300 (range 100 to 600).

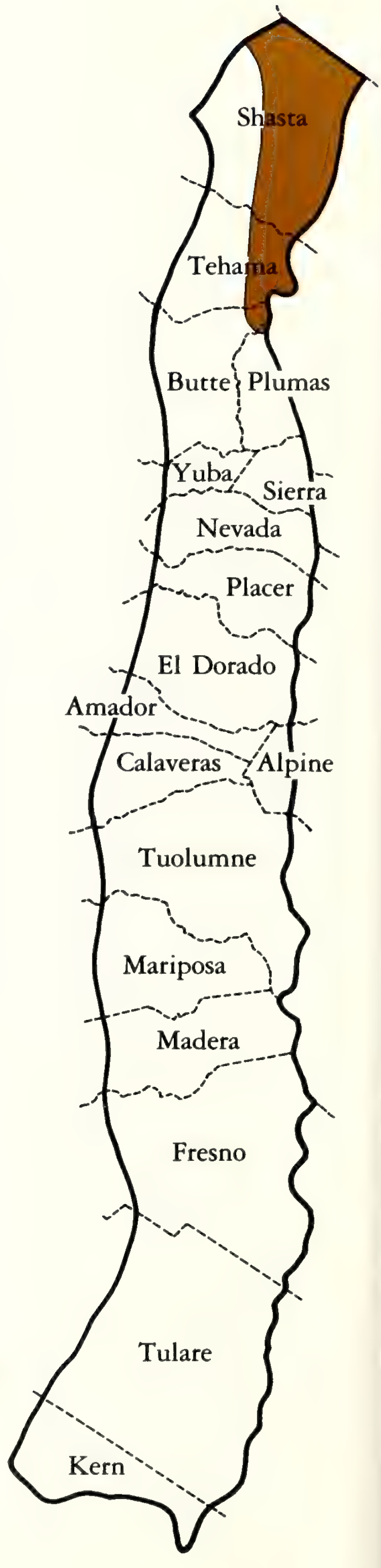
TERRITORY/HOME RANGE: Not thought to be territorial. Home range unknown.

FOOD HABITS: Waits for and pounces on insects and other small animals in water (ponds and streams).

OTHER: Best work done in Washington, but data may not apply to California.

REFERENCES: Slater 1939, Stebbins 1951, 1954a, 1966, 1972; Altig and Dumas 1971.





Leopard Frog

A023 *(Rana pipiens)*

STATUS: No official listed status. Reported in Lake Tahoe Basin, El Dorado County. Present status unknown.

DISTRIBUTION/HABITAT: Found in mountain meadow, riparian deciduous, and mixed-conifer types. Distribution limited to Tahoe Basin. Elevation range 6200 to 7000 ft (1890 to 2130 m).

SPECIAL HABITAT REQUIREMENTS: Streams, rivers, ponds, or lakes.

BREEDING: Eggs laid in open water in May and June, with peak activity around June 1. Mean clutch size 4000 (range 3000 to 6000).

TERRITORY/HOME RANGE: Not territorial, except in vicinity of male. Home range unknown.

FOOD HABITS: Waits for and pounces on insects and other small animals near open water.

OTHER: An introduced species in the Sierra Nevada; might displace native frogs; could be considered a pest.

REFERENCES: Bryant 1917, Stebbins 1954a.

Foothill Yellow-legged Frog

A024 *(Rana boylei)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Native of foothill streams. Found the entire length of the Sierra Nevada in streams and mountain meadows from 1000 to 6000 ft (305 to 1830 m).

SPECIAL HABITAT REQUIREMENTS: Permanent foothill streams.

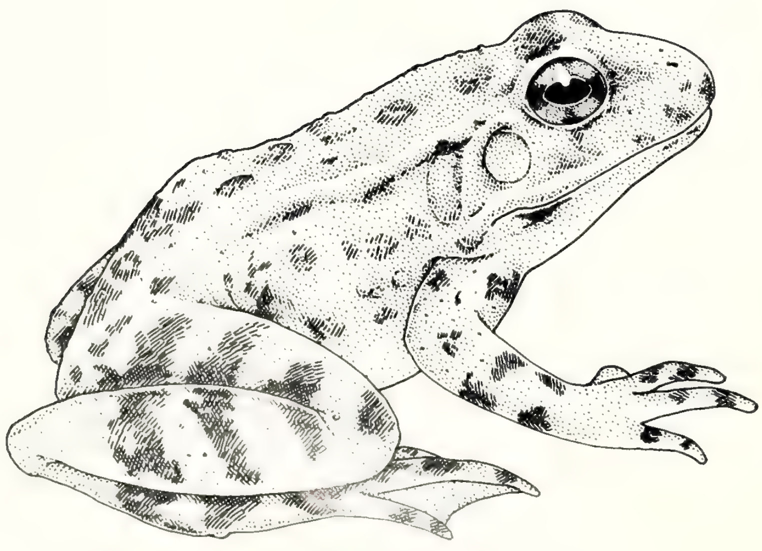
BREEDING: Eggs laid in streams, often where water moves over rocks at increased flow, in April and May. Mean clutch size 200 to 300 eggs (range 100 to 1000).

TERRITORY/HOME RANGE: Not territorial. Home range thought to be small.

FOOD HABITS: Waits for and pounces on any small animal moving at stream edge or in water.

OTHER: Affected by reduced flow in foothill streams.

REFERENCES: Zweifel 1955, 1968a.



Mountain Yellow-legged Frog

A025 *(Rana muscosa)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Found year-round in streams, rivers, ponds, and lakes from 5000 to 13,000 ft (1520 to 3960 m). Prefers mountain meadow, riparian deciduous, and alpine meadow types. Distributed from the southern Sierra Nevada north to Plumas and Butte Counties.

SPECIAL HABITAT REQUIREMENTS: Permanent streams, rivers, ponds, and lakes.

BREEDING: Eggs laid in rivers, streams, ponds, and lakes from May to July, with peak activity in June. Mean clutch size 200 to 300 (range 100 to 500).

TERRITORY/HOME RANGE: Not thought to be territorial; home range thought to be small.

FOOD HABITS: Waits for and pounces on small animals at stream and lake edges.

OTHER: Numbers reduced when trout introduced into high lakes.

REFERENCES: Zweifel 1955, 1968b.

Bullfrog

A026 *(Rana catesbeiana)*

STATUS: No official listed status. Game species (State of California).

DISTRIBUTION/HABITAT: Found year-round in ponds, pools, lakes, ditches, and streams in annual grassland, blue oak savannah, digger pine-oak, and chaparral types. Also found in forested types up to 6000 ft (1830 m). Distributed the entire length of the Sierra Nevada.

SPECIAL HABITAT REQUIREMENTS: Ponds, pools, lakes, ditches, rivers, and streams.

BREEDING: Eggs laid in permanent water from April to June, with peak activity in May. Clutch size numbers in the thousands.

TERRITORY/HOME RANGE: Territory restricted to the vicinity of calling male. Home range size unknown.

FOOD HABITS: A voracious feeder, waits for and pounces on anything it can catch and swallow near pond edges and streams.

OTHER: An introduced species in the Sierra Nevada. Known to be detrimental to native species of frogs. Only a few populations above 4000 ft (1220 m).

REFERENCES: Stebbins 1951, 1954a, 1966, 1972; Moyle 1973.

Western Pond Turtle

R001 *(Clemmys marmorata)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Found year-round in ponds and streams, primarily in the foothills. Also found in suitable habitat in forested types up to 6000 ft (1830 m).

SPECIAL HABITAT REQUIREMENTS: Permanent streams, rivers, ponds, and lakes (may survive long periods of drought by burrowing into mud).

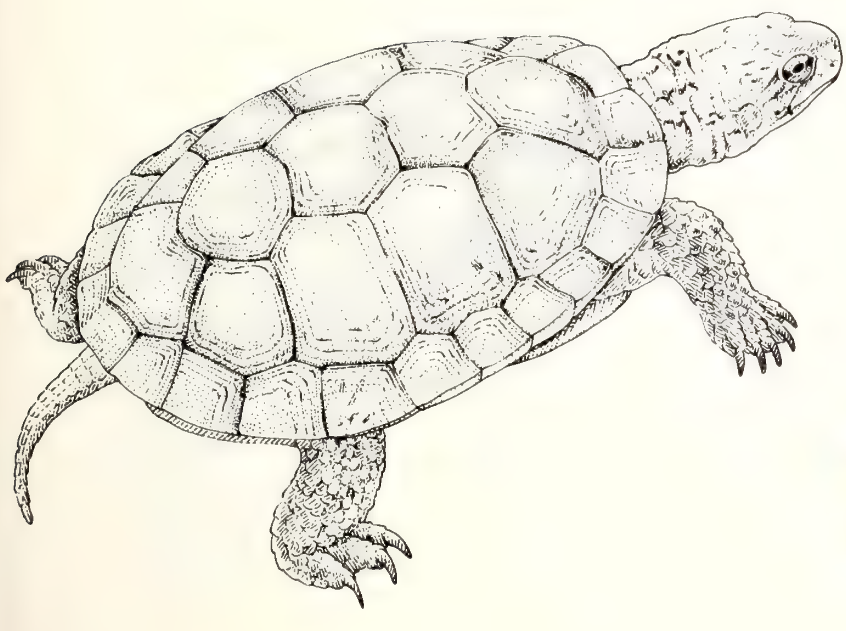
BREEDING: Eggs laid in moist sand or soil from March to May, with peak activity in April. Mean clutch size 7 (range 5 to 11).

TERRITORY/HOME RANGE: May not be territorial. Home range thought to be small.

FOOD HABITS: Searches for aquatic plants, carrion, and insects in streams and ponds.

OTHER: Only turtle in this management area.

REFERENCES: Stebbins 1954a, 1966, 1972; Bury 1970, 1972.



Western Fence Lizard

R002 *(Sceloporus occidentalis)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Found throughout the Sierra Nevada in all successional stages of numerous habitat types up to 9000 ft (2740 m). Prefers annual grassland, blue oak savannah, digger pine-oak, chaparral, and riparian deciduous types. Also found in forested areas.

SPECIAL HABITAT REQUIREMENTS: Rock outcrops and friable soil for breeding.

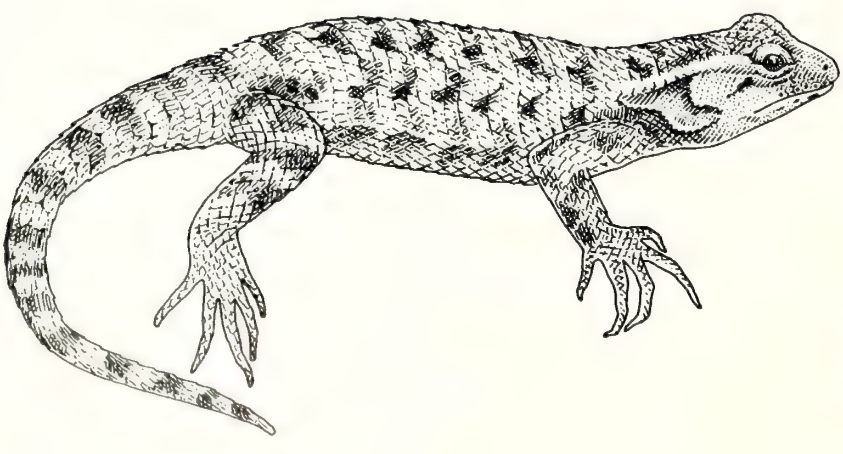
BREEDING: Eggs laid in damp, well-aerated soil from mid-May to mid-July, with peak activity in June. Mean clutch size 9 (range 5 to 15).

TERRITORY/HOME RANGE: Territory thought to be within 25 ft (7.5 m) radius of adult male. Home range estimated to be up to 0.25 acre (0.1 ha).

FOOD HABITS: Waits and searches for insects in rock outcrops.

OTHER: Subspecies, *S. o. taylori,* endemic to the central high Sierra Nevada.

REFERENCES: Stebbins 1954a, 1966, 1972.



Sagebrush Lizard

R003 *(Sceloporus graciosus)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Found in forested areas throughout the Sierra Nevada. Prefers mixed-conifer type in shrub seedling and open, pole-size successional stages. Also found in the black oak woodland and Jeffrey pine types. Elevation range 6000 to 9000 ft (1830 to 2740 m).

SPECIAL HABITAT REQUIREMENTS: Rock outcrops and friable soil for breeding.

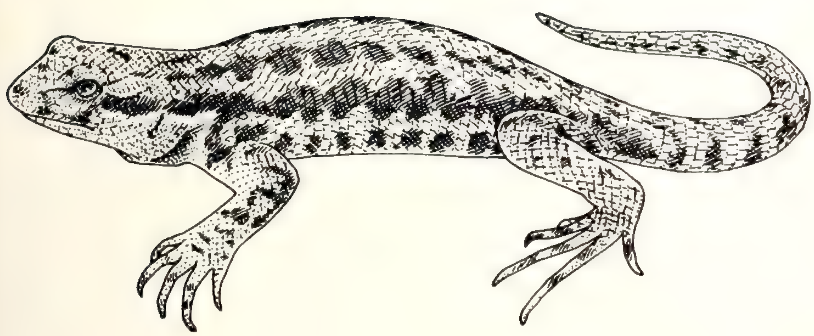
BREEDING: Eggs laid in loose, well-aerated soil in June and July, with peak activity in late June. Mean clutch size 3 or 4 (range 2 to 7).

TERRITORY/HOME RANGE: Territory thought to be within 25 ft (7.5 m) radius of adult male. Home range estimated to be up to 0.5 acre (0.2 ha).

FOOD HABITS: Waits and searches for insects and other small animals in rock outcrops and around bushes.

OTHER:

REFERENCES: Stebbins 1944, 1954a, 1966, 1972.



Side-blotched Lizard

R004 *(Uta stansburiana)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Generally found below 1000 ft (305 m) from Mariposa County southward. Found on the San Joaquin Experimental Range, Madera County, up to 2000 ft (610 m) in annual grassland, blue oak savannah, and digger pine-oak types. No optimum habitat in the Sierra Nevada.

SPECIAL HABITAT REQUIREMENTS: Friable soil for breeding.

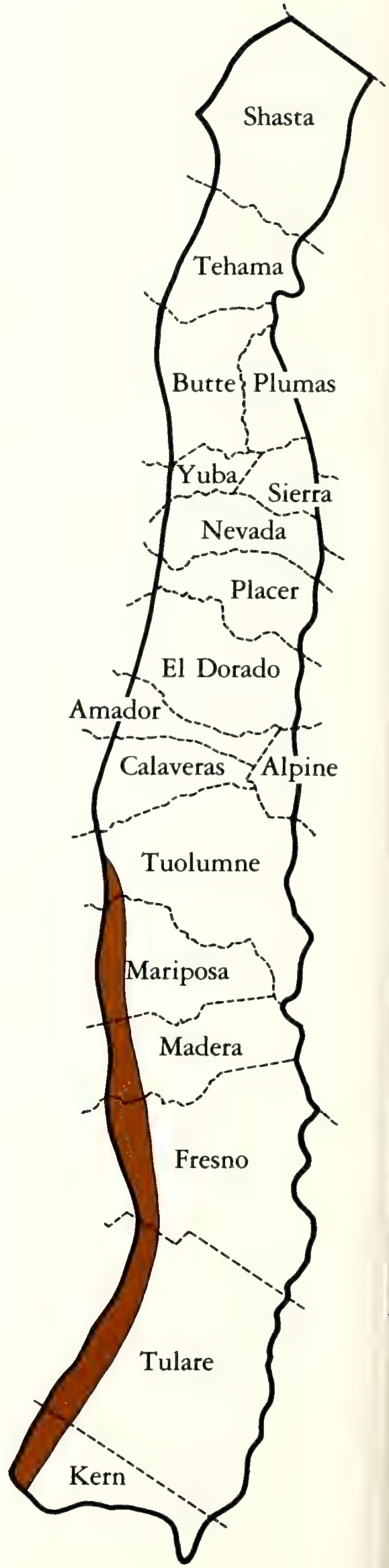
BREEDING: Eggs laid in loose, well-aerated soil from March to June, with peak activity in May. Mean clutch size 4 (range 2 to 5).

TERRITORY/HOME RANGE: May not be territorial. Home range estimated to be up to 0.5 acre (0.2 ha).

FOOD HABITS: Searches for insects on ground surface.

OTHER:

REFERENCES: Stebbins 1954a, Newman and Duncan 1973.



Coast Horned Lizard

R005 *(Phrynosoma coronatum)*

STATUS: No official listed status. Considered fragile.

DISTRIBUTION/HABITAT: Few specimens from the Sierra Nevada, particularly above 1000 ft (305 m). Distributed from Butte County south to Fresno County. Limited habitat in annual grassland, blue oak savannah, and digger pine-oak types. May range up to 4000 ft (1220 m).

SPECIAL HABITAT REQUIREMENTS: Friable soil for breeding.

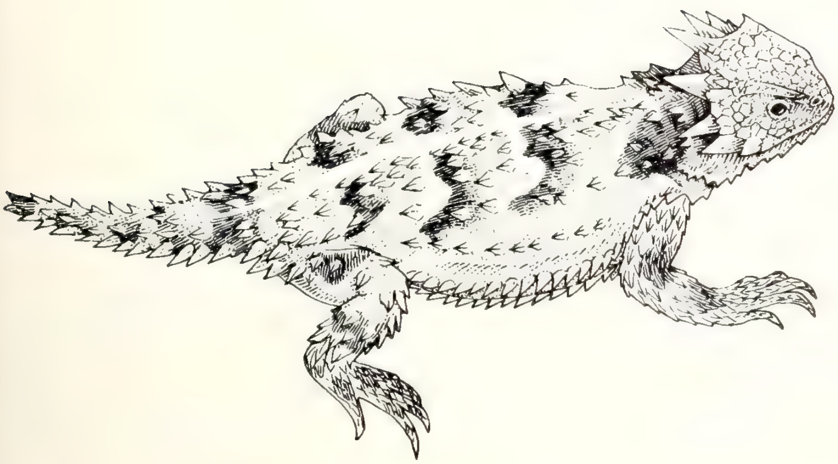
BREEDING: Eggs laid in loose, well-aerated soil from April to June, with peak activity in May. Mean clutch size 11 (range 6 to 16).

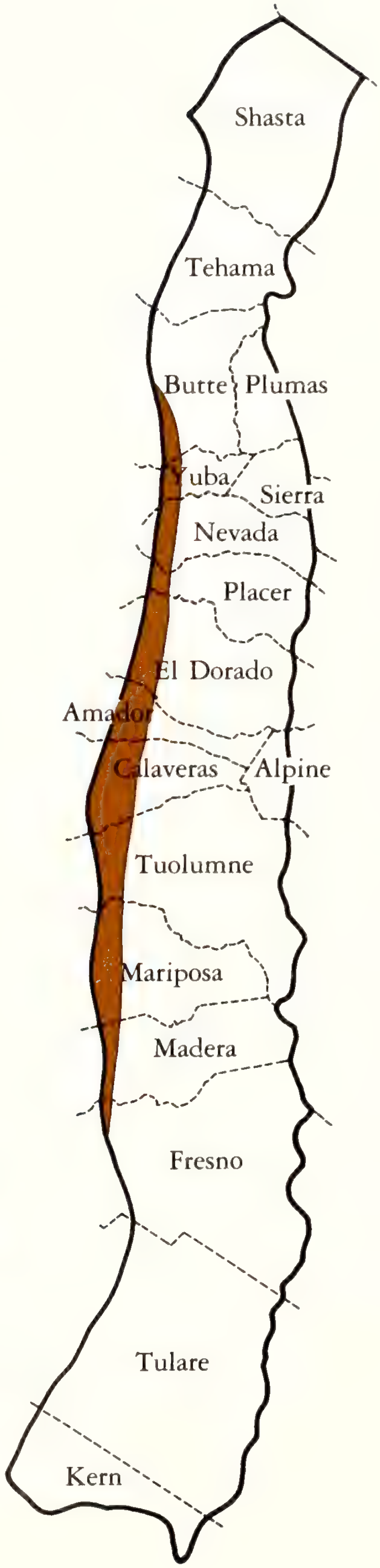
TERRITORY/HOME RANGE: Not thought to be territorial. Home range unknown, but thought to be small.

FOOD HABITS: Waits and searches for insects on ground surface and under surface objects.

OTHER: Notes of sightings above 1000 ft (305 m) should be recorded.

REFERENCES: Stebbins 1954a.





Gilbert's Skink

R006 *(Eumeces gilberti)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Primarily found in foothills up to 6500 ft (1980 m), in all successional stages of numerous habitat types. Prefers chaparral, black oak woodland, and riparian deciduous. Distributed from Butte County southward.

SPECIAL HABITAT REQUIREMENTS:

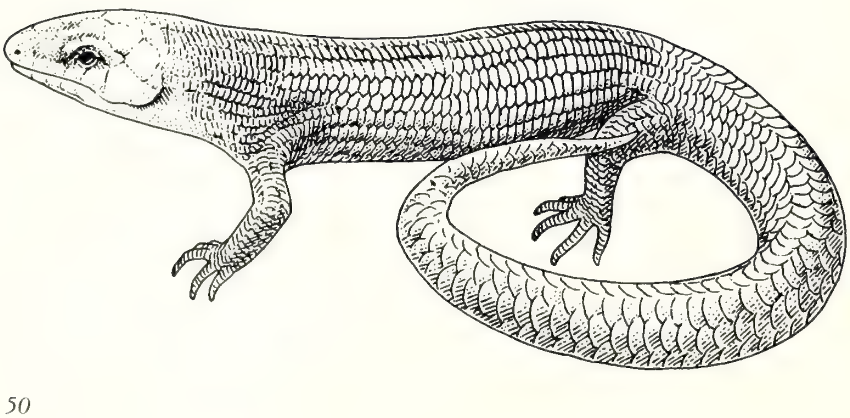
BREEDING: Eggs laid in chambers in loose, aerated soil in June and July, with peak activity around July 1. Mean clutch size 7 (range 5 to 10).

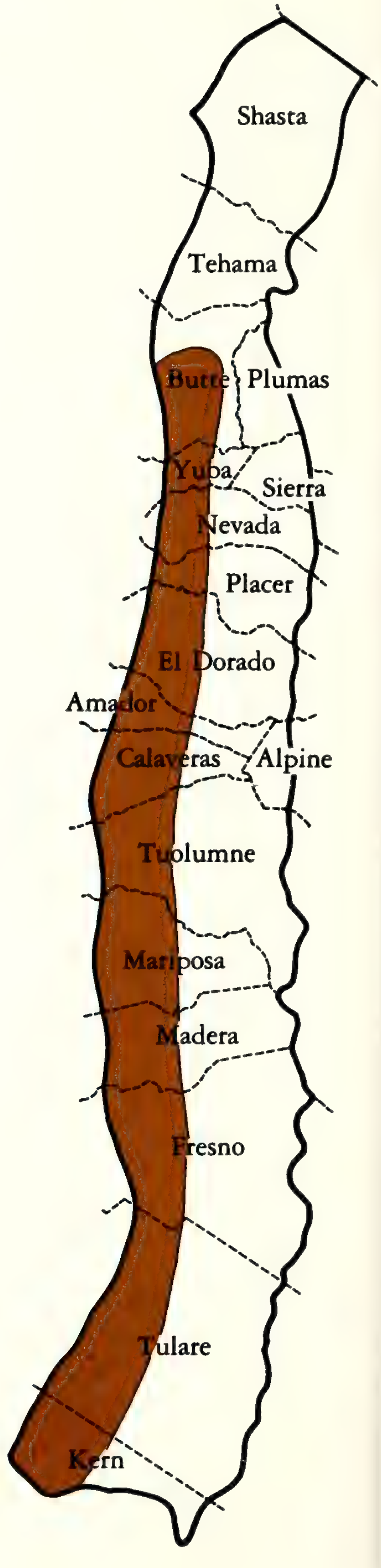
TERRITORY/HOME RANGE: Not thought to be territorial. Home range estimated to be 1 acre (0.4 ha).

FOOD HABITS: Searches for insects and other small animals under leaves and other surface objects.

OTHER:

REFERENCES: Stebbins 1954a.





Western Skink

R007 *(Eumeces skiltonianus)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Primarily found in foothills of the Sierra Nevada from Amador County northward. May range up to 7000 ft (2130 m) in the forested types. Inhabits all successional stages; prefers chaparral, black oak woodland, and riparian types.

SPECIAL HABITAT REQUIREMENTS:

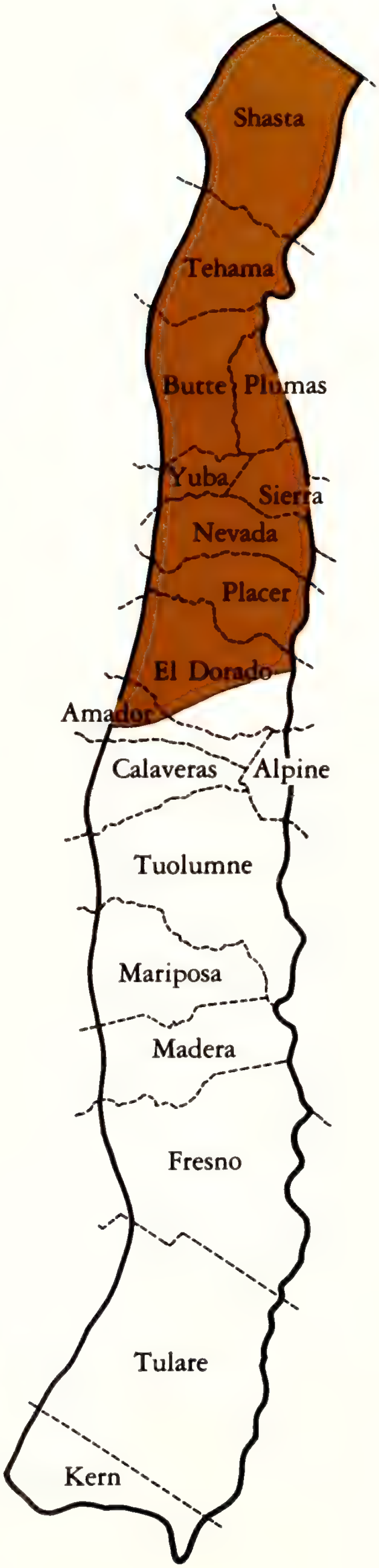
BREEDING: Eggs laid in chambers in loose, aerated soil in June and July, with peak activity around July 1. Mean clutch size 7 (range 5 to 10).

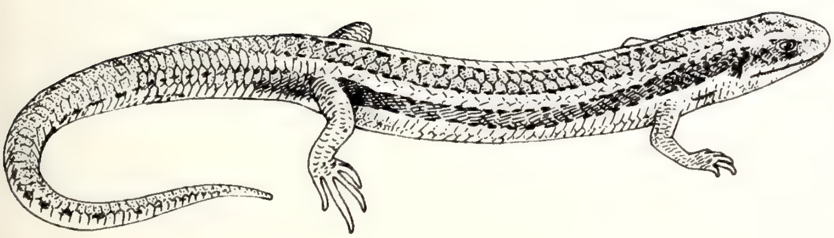
TERRITORY/HOME RANGE: Not thought to be territorial. Home range estimated to be 1 acre (0.4 ha).

FOOD HABITS: Searches for insects and other small animals under leaves and other surface objects.

OTHER:

REFERENCES: Stebbins 1954a.





Western Whiptail

R008 *(Cnemidophorus tigris)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Found in openings in vegetation from foothills to mixed-conifer forests. Prefers annual grassland, chaparral, and early successional stages of blue oak savannah and digger pine-oak types. Distributed the length of the Sierra Nevada up to 7500 ft (2290 m).

SPECIAL HABITAT REQUIREMENTS:

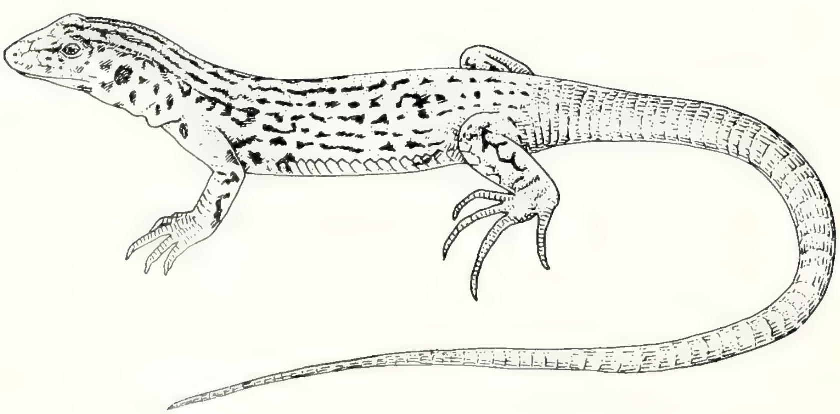
BREEDING: Eggs laid in loose, well-aerated soil in May and June, with peak activity around June 1. Mean clutch size 5 (range 2 to 8).

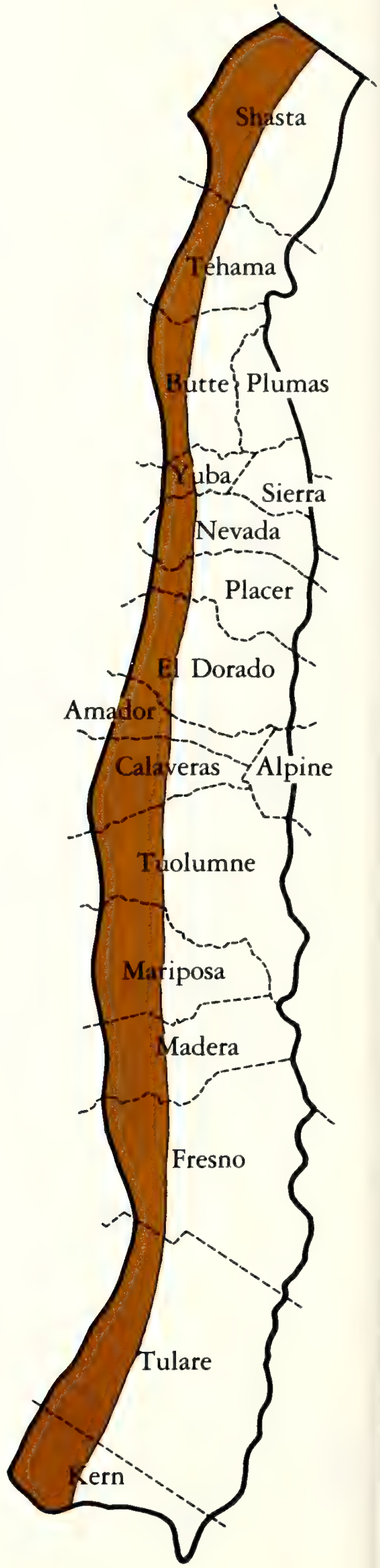
TERRITORY/HOME RANGE: Not thought to be territorial. Home range estimated to be 1 acre (0.4 ha).

FOOD HABITS: Searches for and stalks insects and other small animals on ground surface.

OTHER:

REFERENCES: Stebbins 1954a.





Southern Alligator Lizard

R009 *(Gerrhonotus multicarinatus)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Primarily a foothill species, but can be found up to 6000 ft (1830 m) in the mixed-conifer type. Prefers chaparral and riparian deciduous types. Distributed the length of the Sierra Nevada.

SPECIAL HABITAT REQUIREMENTS:

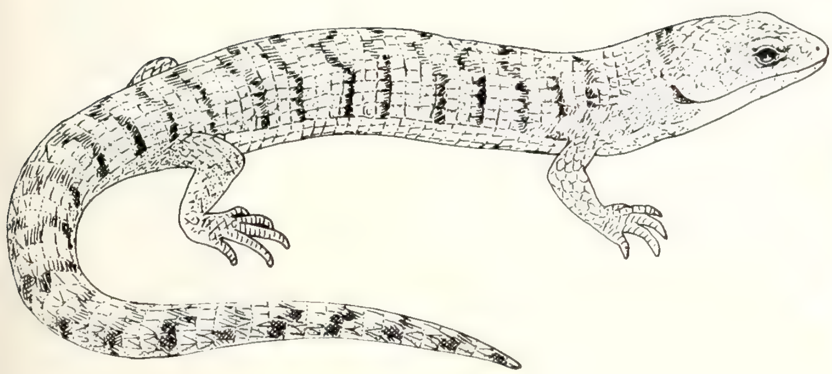
BREEDING: Eggs laid in loose, well-aerated soil from April to June, with peak activity in May. Mean clutch size 12 (range 6 to 20).

TERRITORY/HOME RANGE: Not thought to be territorial. Home range estimated to be 2 acres (0.8 ha).

FOOD HABITS: Searches for insects and other small animals on ground surface and under surface objects.

OTHER:

REFERENCES: Stebbins 1954a.



Northern Alligator Lizard

R010 *(Gerrhonotus coeruleus)*

STATUS: No official listed status. Common in preferred habitat.

DISTRIBUTION/HABITAT: Primarily found in forest areas. Prefers pole to mature successional stages of ponderosa pine, black oak woodland, and mixed-conifer types. Also found in other forested types the length of the Sierra Nevada. Elevational range 1000 (at least in northern counties) to 11,000 ft. (305 to 3350 m).

SPECIAL HABITAT REQUIREMENTS:

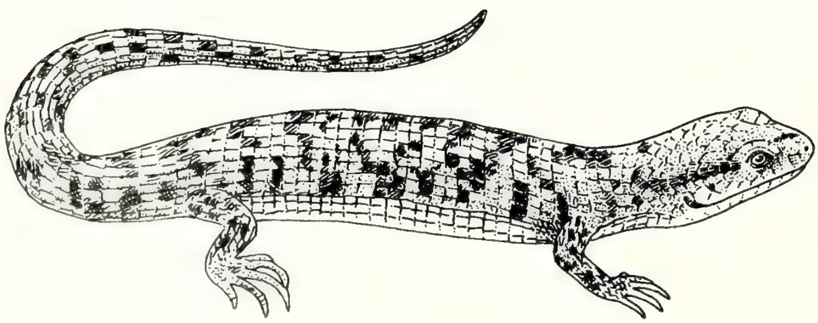
BREEDING: Mates in May and June, with peak activity varying from year-to-year. Young born in fall without use of nest. Mean number of young born 5 (range 2 to 15).

TERRITORY/HOME RANGE: Not territorial. Home range thought to be 1 acre (0.4 ha).

FOOD HABITS: Searches under surface objects for insects and other small animals.

OTHER:

REFERENCES: Stebbins 1954a, Lais 1976.



California Legless Lizard

R011 *(Anniella pulchra)*

STATUS: No official listed status. Considered fragile.

DISTRIBUTION/HABITAT: Restricted to areas of bush lupine in Kaweah River drainage; possibly also found in lower Kern River drainage. Prefers riparian deciduous type. Elevation range unknown, possibly up to 6000 ft (1830 m).

SPECIAL HABITAT REQUIREMENTS: Sandy streams or riverbanks.

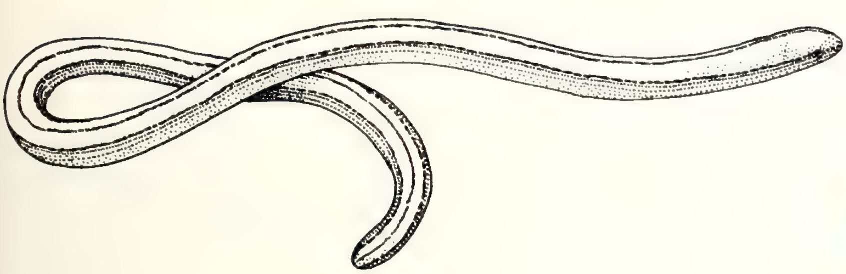
BREEDING: Mates from April to June, with peak activity in May. Young born in damp, loose soil in fall. Mean number of young 2 (range 1 to 4).

TERRITORY/HOME RANGE: Not territorial. Home range unknown, probably restricted.

FOOD HABITS: Searches in loose soil for insects, particularly larvae.

OTHER: Burrowing animal; watch for during excavations.

REFERENCES: Stebbins 1954a.



Rubber Boa

R012 *(Charina bottae)*

STATUS: No official listed status. Considered stable.

DISTRIBUTION/HABITAT: Found near streams and meadows in all forested types; prefers pole to mature successional stages of ponderosa pine, black oak woodland, and mixed-conifer types. Distributed the length of the Sierra Nevada. Elevation jange 5000 to 9000 ft (1520 to 2740 m).

SPECIAL HABITAT REQUIREMENTS:

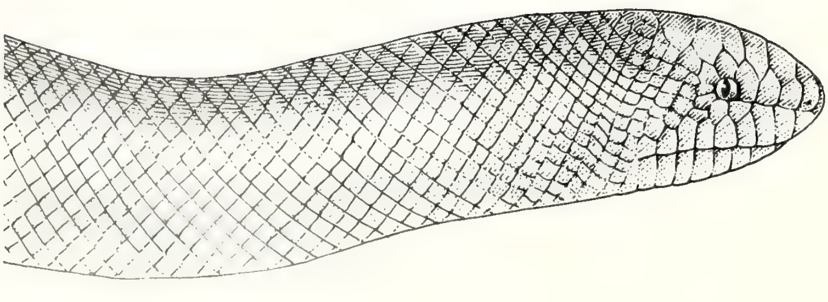
BREEDING: Mates from April to June, with peak activity in May. Young born in early fall in loose, aerated soil. Mean number of young 4 (range 1 to 6).

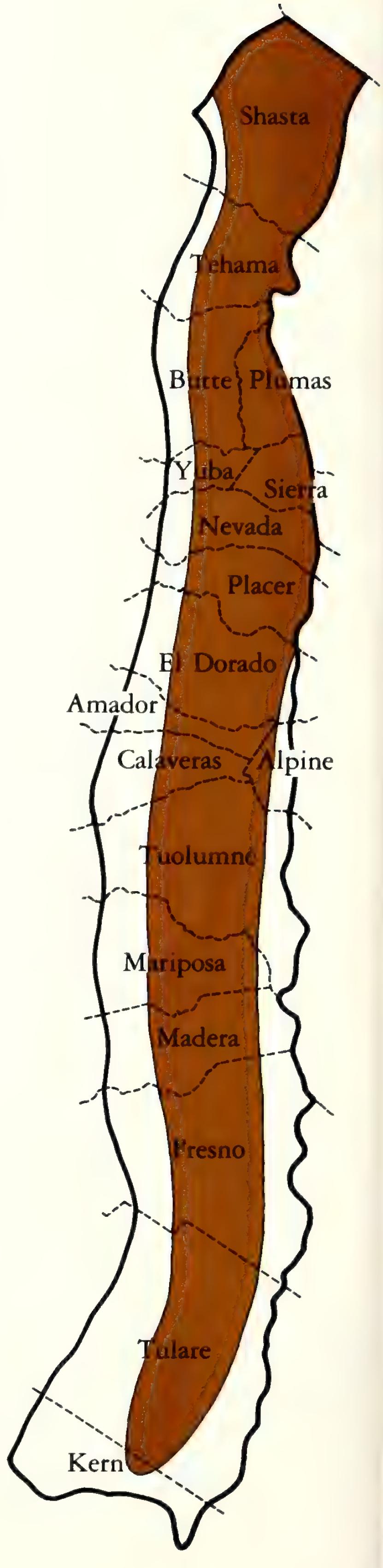
TERRITORY/HOME RANGE: Not territorial. Home range unknown.

FOOD HABITS: Searches for mice, young birds, lizards, and snakes on forest floor and near meadow types.

OTHER: Good burrower.

REFERENCES: Stebbins 1954a.





Ringneck Snake

R013 *(Diadophus punctatus)*

STATUS: No official listed status. Uncommon.

DISTRIBUTION/HABITAT: Usually found on north-facing slopes of foothill canyons; also found up to 6000 ft (1830 m) in mixed-conifer types. Prefers annual grassland, chaparral, and riparian deciduous types. Distributed the length of the Sierra Nevada.

SPECIAL HABITAT REQUIREMENTS: Moist soil related to north-facing slopes.

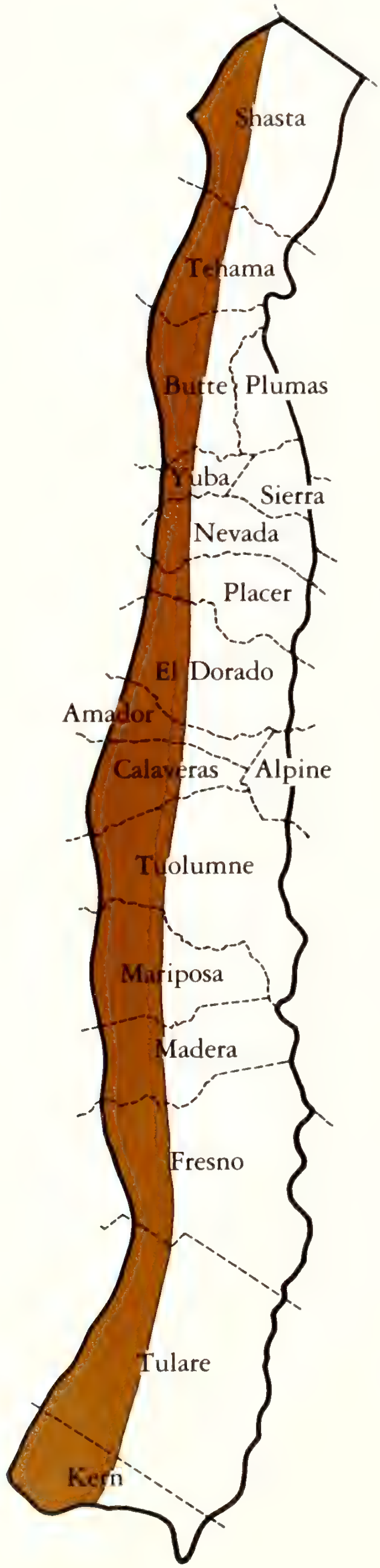
BREEDING: Eggs laid in loose, well-aerated soil from April to June, with peak activity in May. Mean clutch size 2 (range 1 to 4).

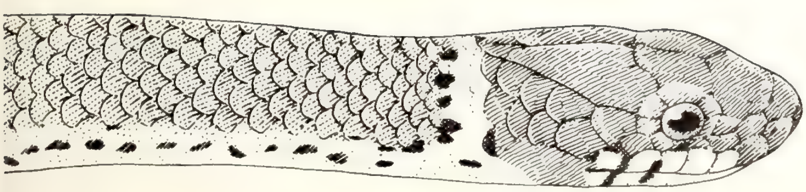
TERRITORY/HOME RANGE: Not thought to be territorial. Home range unknown.

FOOD HABITS: Eats mainly slender salamanders; also treefrogs and small lizards.

OTHER:

REFERENCES: Stebbins 1954a.





Sharp-tailed Snake

R014 *(Contia tenuis)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Found in all successional stages of numerous habitat types up to 7000 ft (2130 m) the length of the Sierra Nevada. Optimum habitat found in riparian deciduous and mountain meadow types. Not found in annual grassland and blue oak savannah types.

SPECIAL HABITAT REQUIREMENTS: Litter and other surface objects.

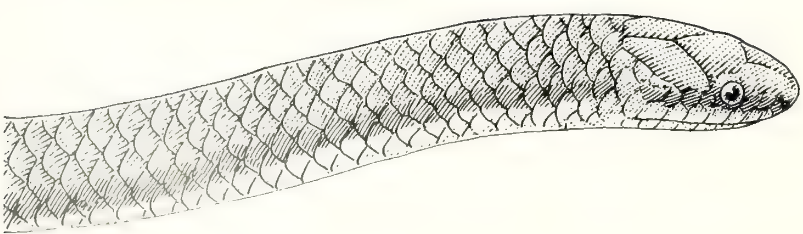
BREEDING: Mates from April to June, with peak activity in May. Eggs laid in summer in loose soil; mean clutch size 3 or 4 (range 2 to 8).

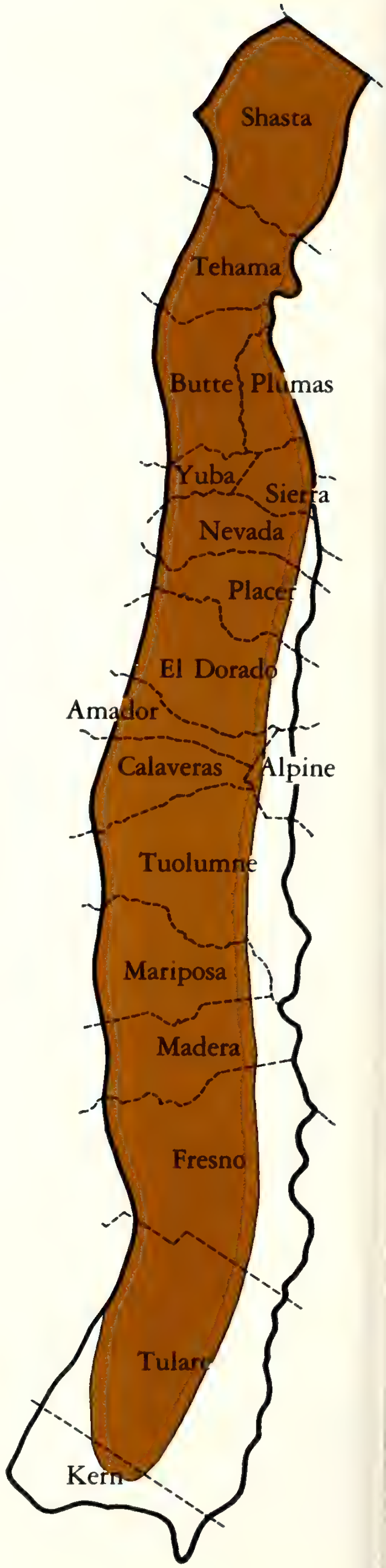
TERRITORY/HOME RANGE: Not thought to be territorial. Home range is unknown; thought to be restricted.

FOOD HABITS: Searches under surface objects for small slugs, slender salamanders, and insects.

OTHER:

REFERENCES: Stebbins 1954a.





Racer

R015 *(Coluber constrictor)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Primarily grassland up into forested areas. Optimum habitat in annual grassland and early successional stages of blue oak savannah types. Most common in the northern Sierra Nevada, with few specimens collected south of Lake Tahoe, El Dorado County. Elevation range to 6000 ft (1830 m).

SPECIAL HABITAT REQUIREMENTS:

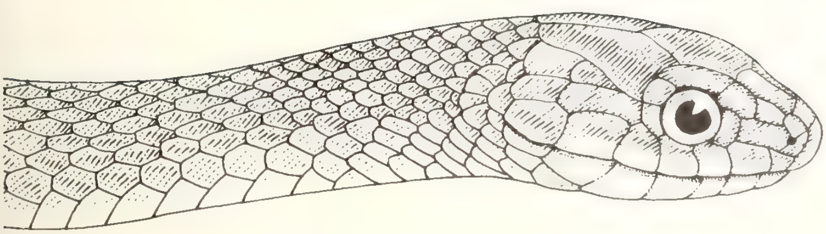
BREEDING: Mates in April and May. Eggs laid in early summer in loose, aerated soil; mean clutch size 18 to 20 (range 12 to 24).

TERRITORY/HOME RANGE: Not thought to be territorial. Home range unknown, may be extensive.

FOOD HABITS: Searches on ground surface for mice, fledgling birds, and lizards.

OTHER:

REFERENCES: Stebbins 1954a.



Coachwhip

R016 *(Masticophis flagellum)*

STATUS: No official listed status. Very few records from the Sierra Nevada.

DISTRIBUTION/HABITAT: Not usually found in the Sierra Nevada above 1000 ft (305 m). No optimum habitat in the Sierra Nevada.

SPECIAL HABITAT REQUIREMENTS:

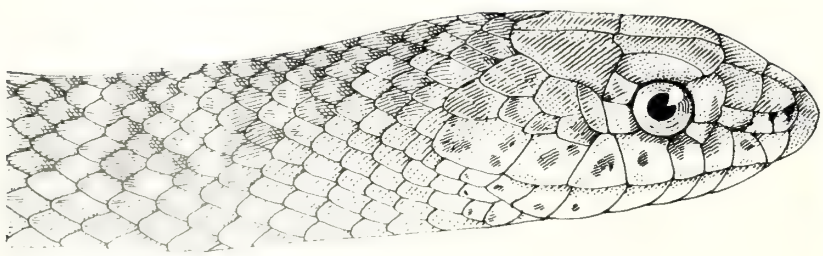
BREEDING: Mates in April and May, with peak activity near April 1. Mean clutch size 8 (range 4 to 11).

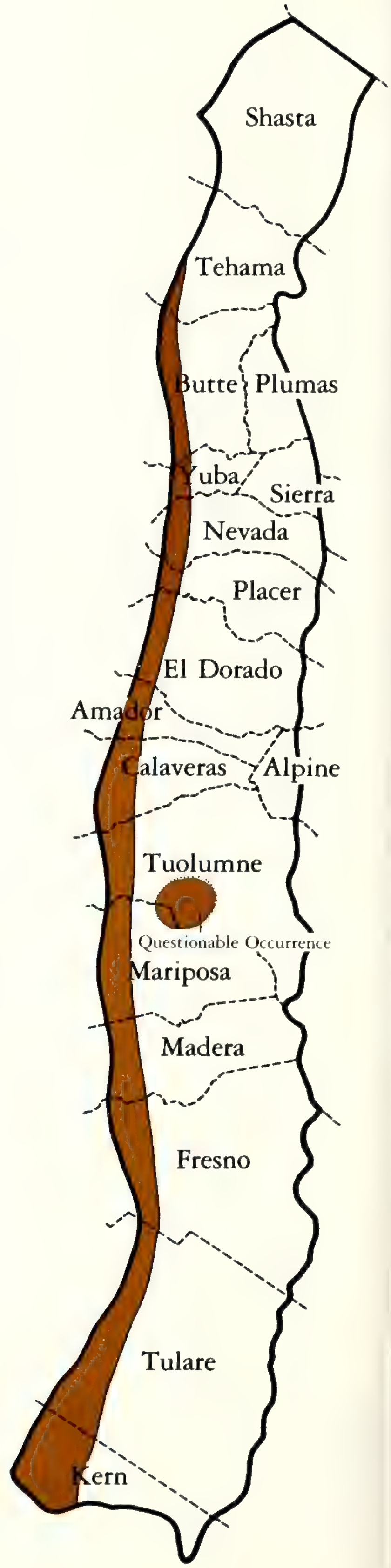
TERRITORY/HOME RANGE: Not territorial. Home range unknown, thought to be large.

FOOD HABITS: Stalks and searches for rodents, birds, bird eggs, and lizards on ground surface and under objects.

OTHER: Reported at 4000 ft (1220 m) in Yosemite Valley, Tuolumne County.

REFERENCES: Stebbins 1954a, 1966, 1972; Wilson 1973.





Striped Racer

R017 *(Masticophis lateralis)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Primarily chaparral with optimum habitat also in riparian deciduous type. Less commonly found in other habitat types. Found the length of the Sierra Nevada up to 5500 ft (1680 m).

SPECIAL HABITAT REQUIREMENTS:

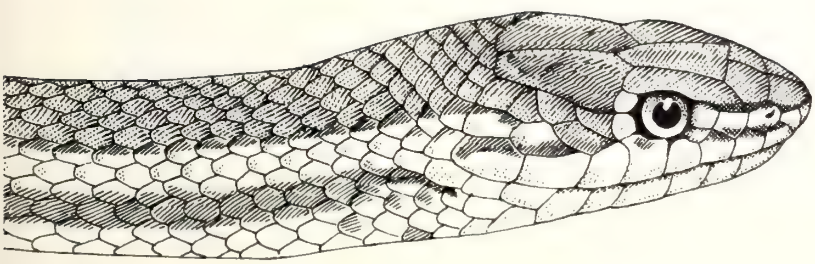
BREEDING: Mates in April and May, with peak activity near May 1. Eggs laid in summer in loose, well-aerated soil. Mean clutch size 6 (range 4 to 10).

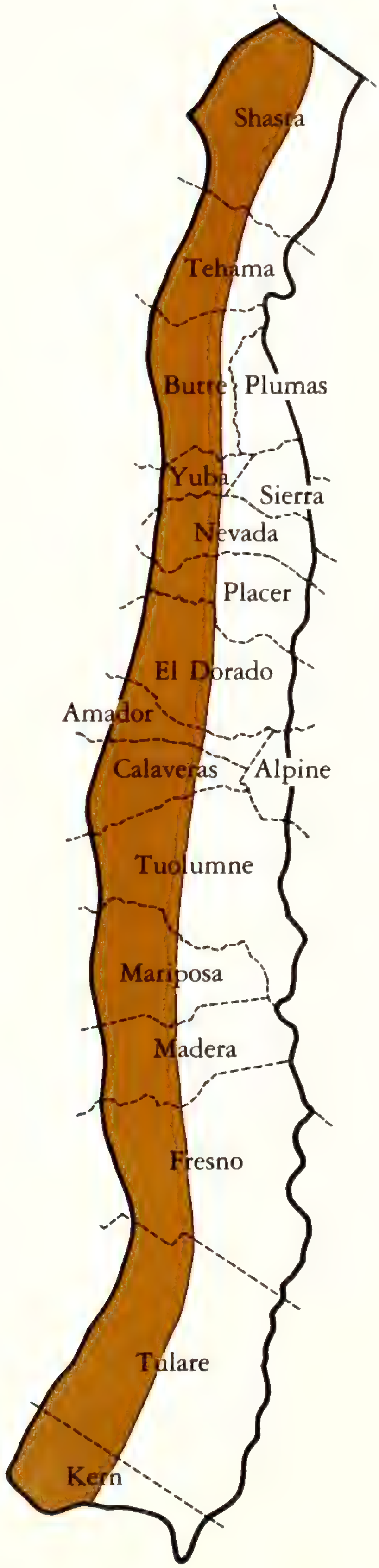
TERRITORY/HOME RANGE: Territory unknown; may not be territorial. Home range unknown; may be extensive.

FOOD HABITS: Searches in bushes and on ground surface for snakes, lizards, rodents, and fledgling birds.

OTHER:

REFERENCES: Stebbins 1954a.





Gopher Snake

R018 *(Pituophis melanoleucus)*

STATUS: No official listed status. A common, widespread species.

DISTRIBUTION/HABITAT: Found in many habitats the length of the Sierra Nevada up to 7000 ft (2130 m). Optimum habitat in blue oak savannah, digger pine-oak, chaparral, and riparian deciduous types.

SPECIAL HABITAT REQUIREMENTS:

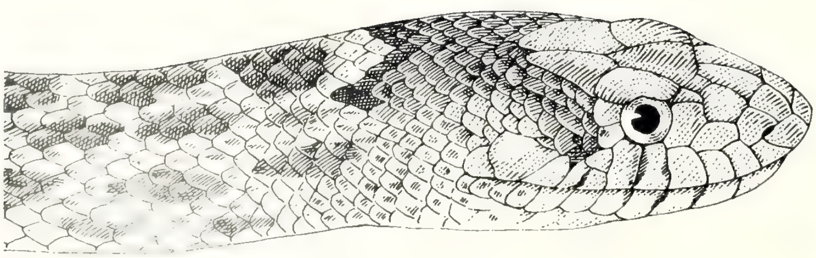
BREEDING: Mates from April to June, with peak activity in May. Eggs laid in damp, loose, well-aerated soil in summer. Mean clutch size 7 (range 3 to 12).

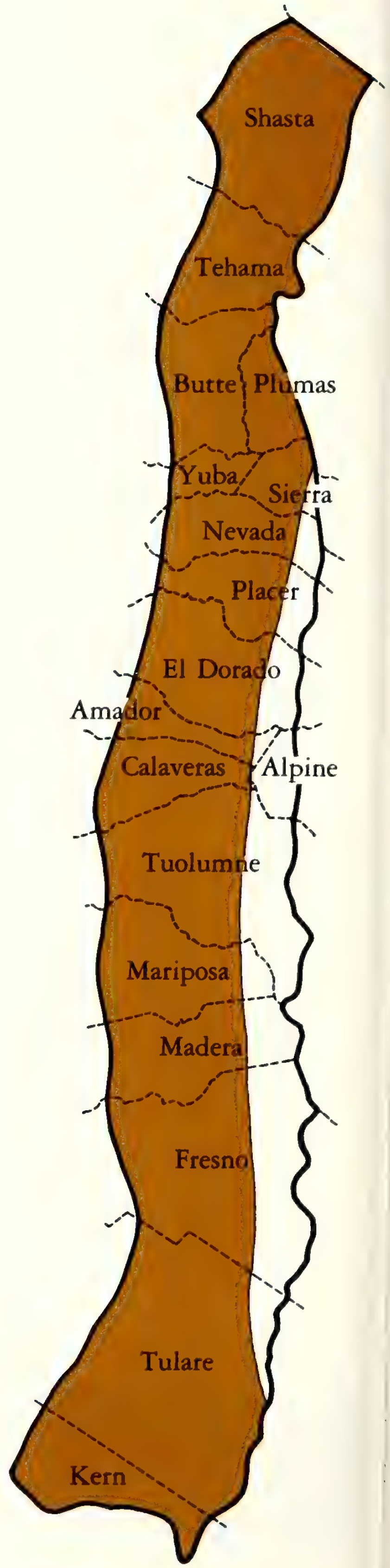
TERRITORY/HOME RANGE: Not thought to be territorial. Home range unknown.

FOOD HABITS: Searches on surface and under objects for small mammals (squirrels, mice, gophers, and others).

OTHER:

REFERENCES: Stebbins 1954a.





Common Kingsnake

R019 *(Lampropeltis getulus)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Found the length of the Sierra Nevada in annual grasslands, blue oak savannah, digger pine-oak, chaparral, and riparian deciduous types. Also found in forested areas up to 6000 ft (1830 m). Observed in all successional stages of its many habitats.

SPECIAL HABITAT REQUIREMENTS:

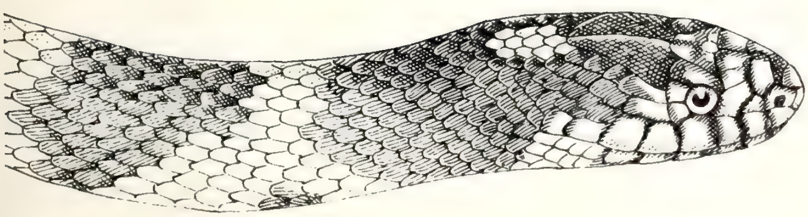
BREEDING: Mates from March to May, with peak activity in April. Eggs laid in loose, well-aerated soil in summer. Mean clutch size 9 (range 6 to 12).

TERRITORY/HOME RANGE: Territory unknown; may not be territorial. Home range unknown; may be extensive.

FOOD HABITS: Searches under surface objects for snakes, lizards, and mice.

OTHER:

REFERENCES: Stebbins 1954a.



California Mountain Kingsnake

R020 *(Lampropeltis zonata)*

STATUS: No official listed status; may be considered fragile.

DISTRIBUTION/HABITAT: Usually found near streams of upper foothills the length of the Sierra Nevada. Found in numerous habitats; optimum habitats are mountain meadow and riparian deciduous types. Elevation range 1000 to 6500 ft (305 to 1980 m).

SPECIAL HABITAT REQUIREMENTS:

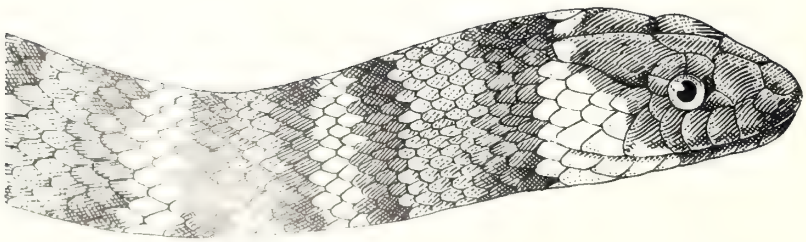
BREEDING: Mates in April and May, with peak activity near May 1. Eggs laid in loose, well-aerated soil in summer. Mean clutch size 6 (range 4 to 8).

TERRITORY/HOME RANGE: Territory unknown; may not be territorial. Home range unknown.

FOOD HABITS: Searches under surface objects for lizards, small snakes, and bird eggs.

OTHER: Bright colors make this species a target of pet collectors.

REFERENCES: Stebbins 1954a, Zweifel 1974.



Long-nosed Snake

R021 *(Rhinocheilus lecontei)*

STATUS: No official listed status. May be considered fragile.

DISTRIBUTION/HABITAT: Seldom recorded above 1000 ft (305 m). No optimum habitat in the Sierra Nevada.

SPECIAL HABITAT REQUIREMENTS:

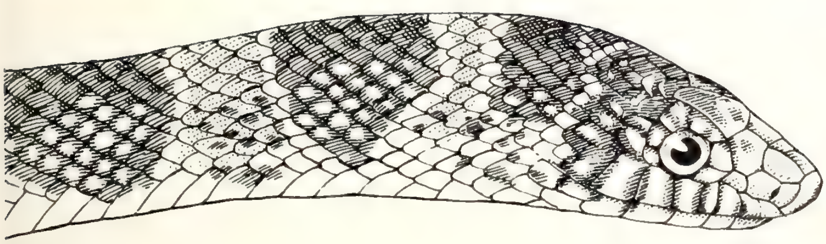
BREEDING: Mates from March to May, with peak activity in April. Eggs laid in loose, moist, well-aerated soil. Mean clutch size 5 (range 3 to 8).

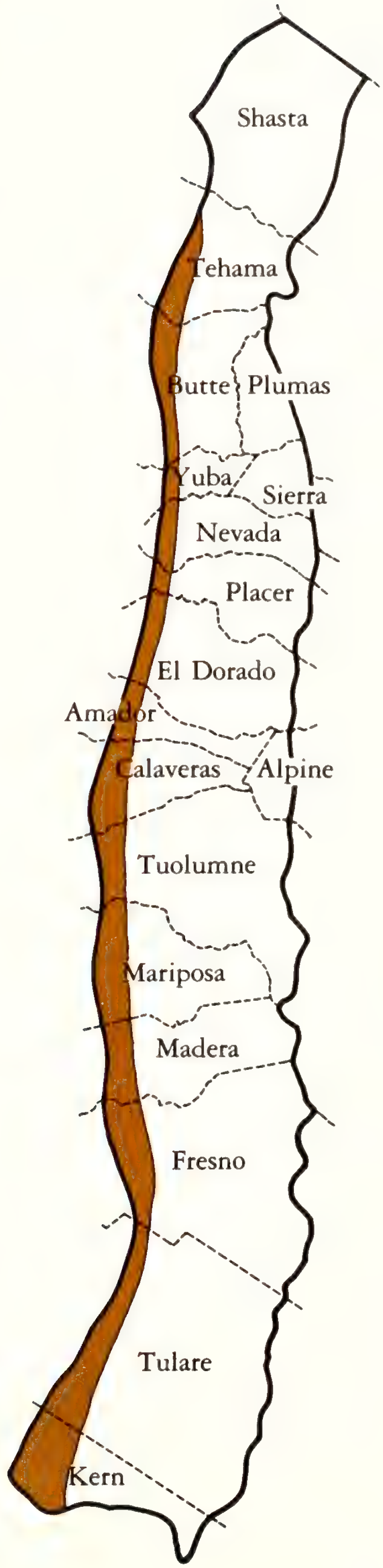
TERRITORY/HOME RANGE: Not territorial. Home range unknown.

FOOD HABITS: Stalks and searches for lizards, small mammals, and insects on ground surface and under objects.

OTHER: Once recorded at San Joaquin Experimental Range, Madera County.

REFERENCES: Stebbins 1954a, 1966, 1972; Medica 1975.





Common Garter Snake

R022 *(Thamnophis sirtalis)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Usually found in foothill streams and ponds, with optimum habitat in annual grassland, blue oak savannah, digger pine-oak, chaparral, and riparian deciduous types. Found the length of the Sierra Nevada at elevations up to 6000 ft (1830 m).

SPECIAL HABITAT REQUIREMENTS: Streams, rivers, ponds, or lakes.

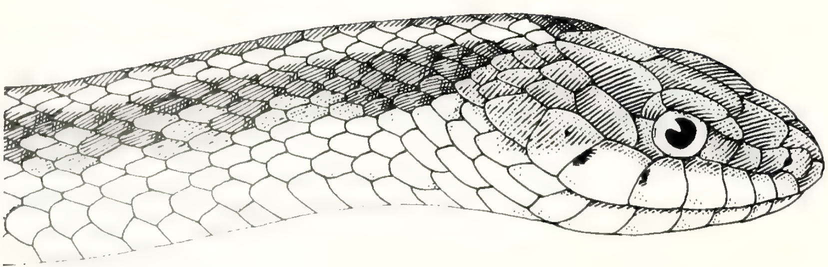
BREEDING: Mates from mid-March to June, with peak activity in April. Young born in summer without nest. Mean number of young born 24 (range 8 to 51).

TERRITORY/HOME RANGE: Territory unknown, may not be territorial. Home range unknown.

FOOD HABITS: Searches in streams and along stream edges for treefrogs, fish, and mice.

OTHER:

REFERENCES: Stebbins 1954a, 1966, 1972; White and Kolb 1974.



Western Terrestrial Garter Snake

R023 *(Thamnophis elegans)*

STATUS: No official status. Common in preferred habitat.

DISTRIBUTION/HABITAT: Found in streams and lakes primarily in the mid- and high-Sierra Nevada. Optimum habitat in riparian deciduous, mountain meadow, and alpine meadow types; may be found in all successional stages of all habitat types from 1000 (at least in northern counties) to 12,000 ft (305 to 3660 m) northward from mid-Tulare County.

SPECIAL HABITAT REQUIREMENTS: Permanent streams, rivers, ponds or lakes for feeding.

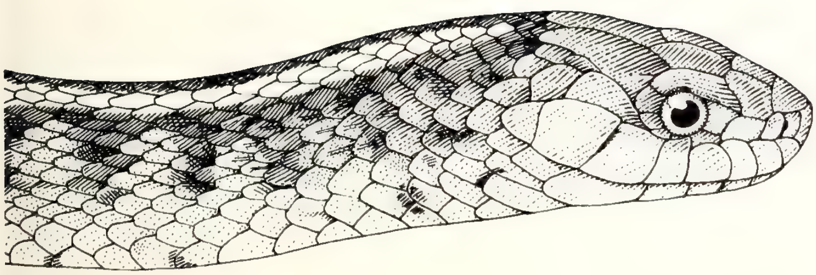
BREEDING: Mates from April to June, with peak activity in May, depending on year and elevation. Young born without nest in summer. Mean number of young born 20 (range 12 to 30).

TERRITORY/HOME RANGE: Territory unknown; may not be territorial. Home range unknown, probably restricted.

FOOD HABITS: Waits and searches for tadpoles, yellow-legged frogs, treefrogs, and fish in lakes, streams, and meadows; also catches mice.

OTHER:

REFERENCES: Stebbins 1954a, White and Kolb 1974.



Western Aquatic Garter Snake

R024 *(Thamnophis couchi)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Usually found in foothill streams and ponds; optimum habitat in blue oak savannah, digger pine-oak, chaparral, mountain meadow, and riparian deciduous types. Also found in forested types up to 6000 ft (1830 m) throughout the Sierra Nevada.

SPECIAL HABITAT REQUIREMENTS: Permanent streams, rivers, ponds, or lakes.

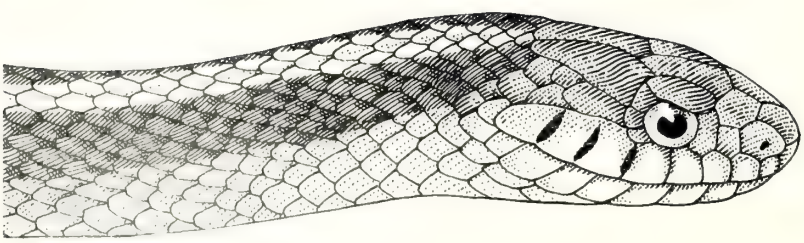
BREEDING: Mates from mid-March to early June, with peak activity in April. Young born without nest in summer. Mean number born 20 (range 10 to 30).

TERRITORY/HOME RANGE: Territory unknown, may not be territorial. Home range unknown.

FOOD HABITS: Searches in streams and along stream edges for fish, frogs, and mice.

OTHER:

REFERENCES: Stebbins 1954a.



Western Black-headed Snake

R025 *(Tantilla planiceps)*

STATUS: No official listed status. May be considered fragile.

DISTRIBUTION/HABITAT: Restricted to Kaweah River drainage, Tulare and Kern Counties, below 2000 ft (610 m). No optimum habitat known in the Sierra Nevada.

SPECIAL HABITAT REQUIREMENTS: Unknown.

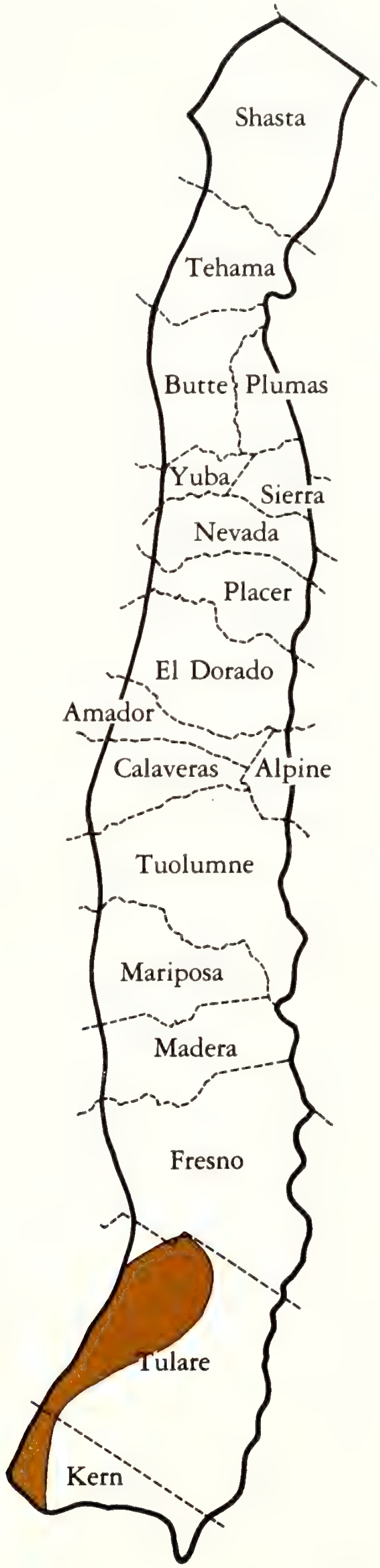
BREEDING: Eggs laid from May to June, with peak activity in June. Mean clutch size 1 or 2 (range unknown in Sierra Nevada). Nest site requirements unknown in Sierra Nevada.

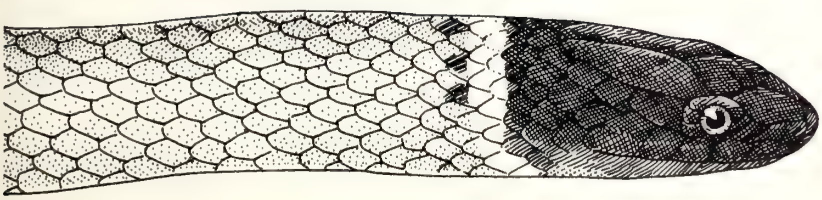
TERRITORY/HOME RANGE: Not thought to be territorial. Home range unknown.

FOOD HABITS: Searches for insects, particularly beetle larvae, under surface objects.

OTHER: Few specimens collected from the Sierra Nevada. Very little known.

REFERENCES: Stebbins 1954a, Tanner 1966, Basey 1976.





Night Snake

R026 *(Hypsiglena torquata)*

STATUS: No official listed status. May be considered fragile.

DISTRIBUTION/HABITAT: Found infrequently in numerous habitats up to 6000 ft (1830 m) throughout the Sierra Nevada. Optimum habitat the chaparral type.

SPECIAL HABITAT REQUIREMENTS: Crevices in rock outcrops.

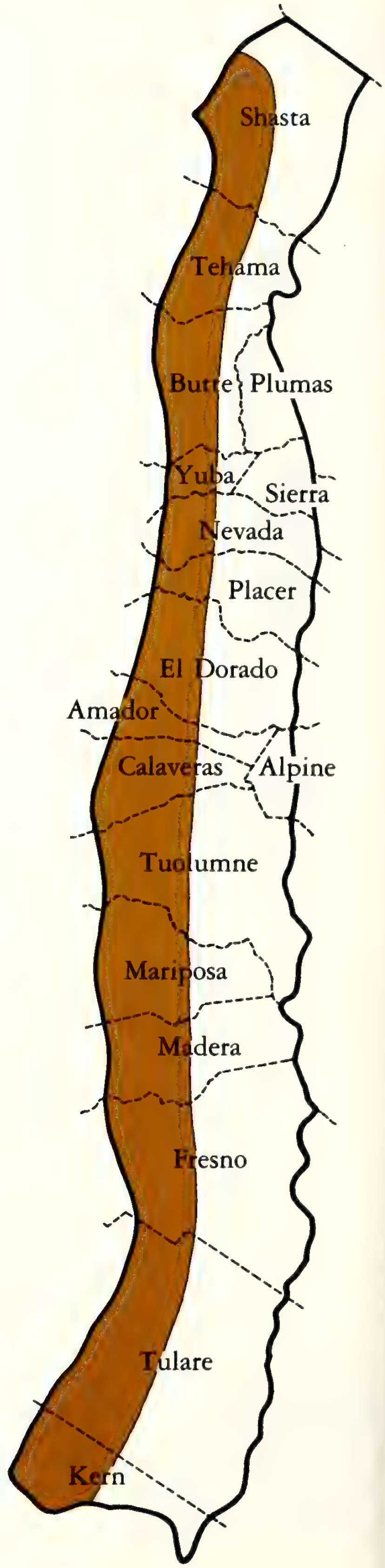
BREEDING: Breeds from April to July, with peak activity in May. Eggs laid in rocky areas where cracks run underground; also found in mines. Mean clutch size 5 (range 4 to 8).

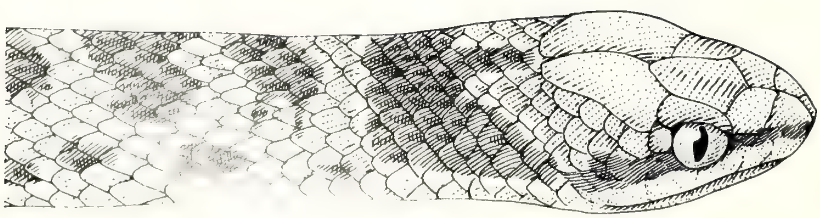
TERRITORY/HOME RANGE: Not thought to be territorial. Home range unknown, may be restricted.

FOOD HABITS: Searches under surface objects and underground for small lizards and slender salamanders.

OTHER: Needs further research on habitat requirements; should be watched for in roadbuilding operations. Little known about requirements for survival.

REFERENCES: Stebbins 1954a.





Western Rattlesnake

R027 *(Crotalus viridis)*

STATUS: No official listed status. Common in preferred habitat.

DISTRIBUTION/HABITAT: Often found in rock outcrops in many habitats. Optimum habitat in annual grassland, blue oak savannah, digger pine-oak, chaparral, and riparian deciduous types. May be found in other habitat types up to 11,000 ft (3350 m). Distributed the length of the Sierra Nevada.

SPECIAL HABITAT REQUIREMENTS: Rock outcrops.

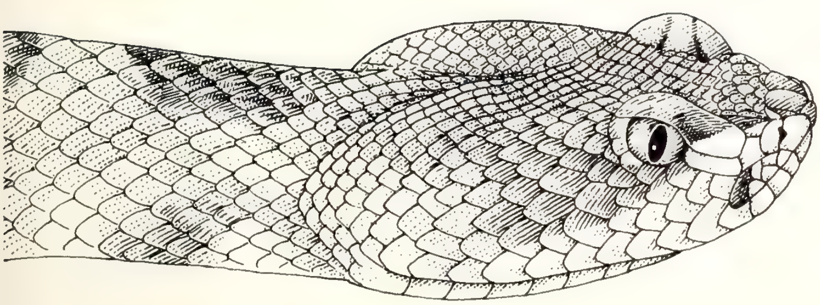
BREEDING: Mates from March to May, with peak activity usually in April, but peak varies from year to year. Young born without nest in fall. Mean number born 11 (range 4 to 21).

TERRITORY/HOME RANGE: Probably not territorial. Home range estimated to be 3 acres (1.2 ha). (Fitch and Glading 1947).

FOOD HABITS: Waits and searches on ground surface and in burrows for rodents (ground squirrels and mice primarily).

OTHER:

REFERENCES: Fitch and Glading 1947, Fitch 1949, Klauber 1972.



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Birds

Jared Verner, Edward C. Beedy, Stephen L. Granholm, Lyman V. Ritter, and *Edward F. Toth*

This chapter offers information on the status, distribution (by habitat type and seral stage), and basic life history for each of 208 species of birds that are found in the western Sierra Nevada. Many of the data came from the literature, although the professional ornithologists involved with this project drew upon extensive personal experience with birds in the Sierra Nevada. Knowledge of the details of bird life in the western Sierra Nevada is scanty at best. Pertinent data on life histories of many species simply were unavailable, while for a majority of those species for which data are presented, the studies cited were done somewhere other than in the western Sierra Nevada. Even assignment of species to habitat types and seral stages was based less on solid information available in the literature, and more on the field experience and judgment of those involved in the project. Therefore, the information reported here is subject to refinement, correction, and revision.

At least 57 additional bird species have been reported five or fewer times in the western Sierra Nevada, and these are simply listed as "accidentals" in the section on Rare Species. The accidental list, of course, will never be complete, as birds are highly mobile animals that not uncommonly turn up well beyond the limits of their normal range. We see no need to manage our lands with such accidentals in mind.

Classification and nomenclature followed here are based on the Checklist of North American Birds (American Ornithologists' Union Checklist Committee 1957) and supplements 32 and 33 (A.O.U. Checklist Committee 1973, 1976). The species are arranged in phylogenetic order and numbered in sequence, with the prefix "B", for purposes of internal cross-referencing and computer access coding.

Species List

B001	Eared Grebe	*Podiceps nigricollis*
B002	Western Grebe	*Aechmophorus occidentalis*
B003	Pied-billed Grebe	*Podilymbus podiceps*
B004	Great Blue Heron	*Ardea herodias*
B005	Green Heron	*Butorides striatus*
B006	Black-crowned Night Heron	*Nycticorax nycticorax*
B007	Whistling Swan	*Olor columbianus*
B008	Canada Goose	*Branta canadensis*
B009	Snow Goose	*Chen caerulescens*
B010	Mallard	*Anas platyrhynchos*
B011	Pintail	*Anas acuta*
B012	Green-winged Teal	*Anas crecca*
B013	Cinnamon Teal	*Anas cyanoptera*
B014	American Wigeon	*Anas americana*
B015	Northern Shoveler	*Anas clypeata*
B016	Wood Duck	*Aix sponsa*
B017	Redhead	*Aythya americana*
B018	Ring-necked Duck	*Aythya collaris*
B019	Canvasback	*Aythya valisineria*
B020	Lesser Scaup	*Aythya affinis*
B021	Barrow's Goldeneye	*Bucephala islandica*
B022	Bufflehead	*Bucephala albeola*
B023	Harlequin Duck	*Histrionicus histrionicus*
B024	Ruddy Duck	*Oxyura jamaicensis*
B025	Hooded Merganser	*Lophodytes cucullatus*
B026	Common Merganser	*Mergus merganser*
B027	Turkey Vulture	*Cathartes aura*
B028	California Condor	*Gymnogyps californianus*
B029	White-tailed Kite	*Elanus leucurus*
B030	Goshawk	*Accipiter gentilis*
B031	Sharp-shinned Hawk	*Accipiter striatus*
B032	Cooper's Hawk	*Accipiter cooperi*
B033	Red-tailed Hawk	*Buteo jamaicensus*
B034	Red-shouldered Hawk	*Buteo lineatus*
B035	Swainson's Hawk	*Buteo swainsoni*
B036	Golden Eagle	*Aquila chrysaetos*
B037	Bald Eagle	*Haliaeetus leucocephalus*
B038	Marsh Hawk	*Circus cyaneus*
B039	Osprey	*Pandion haliaetus*
B040	Prairie Falcon	*Falco mexicanus*
B041	Peregrine Falcon	*Falco peregrinus*
B042	Merlin	*Falco columbarius*
B043	American Kestrel	*Falco sparverius*
B044	Blue Grouse	*Dendragapus obscurus*
B045	White-tailed Ptarmigan	*Lagopus leucurus*
B046	California Quail	*Lophortyx californicus*
B047	Mountain Quail	*Oreortyx pictus*
B048	Chukar	*Alectoris chukar*
B049	Turkey	*Meleagris gallopavo*
B050	Virginia Rail	*Rallus limicola*
B051	American Coot	*Fulica americana*
B052	Killdeer	*Charadrius vociferus*
B053	Common Snipe	*Capella gallinago*
B054	Spotted Sandpiper	*Actitus macularia*
B055	American Avocet	*Recurvirostra americana*
B056	Wilson's Phalarope	*Steganopus tricolor*
B057	California Gull	*Larus californicus*
B058	Ring-billed Gull	*Larus delawarensis*
B059	Band-tailed Pigeon	*Columba fasciata*
B060	Mourning Dove	*Zenaida macroura*
B061	Roadrunner	*Geococcyx californianus*
B062	Barn Owl	*Tyto alba*
B063	Screech Owl	*Otus asio*
B064	Flammulated Owl	*Otus flammeolus*
B065	Great Horned Owl	*Bubo virginianus*
B066	Pygmy Owl	*Glaucidium gnoma*
B067	Burrowing Owl	*Athene cunicularia*
B068	Spotted Owl	*Strix occidentalis*
B069	Great Gray Owl	*Strix nebulosa*
B070	Long-eared Owl	*Asio otus*
B071	Short-eared Owl	*Asio flammeus*
B072	Saw-whet Owl	*Aegolius acadicus*

B073 Poor-will
Phalaenoptilus nuttallii

B074 Common Nighthawk
Chordeiles minor

B075 Black Swift
Cypseloides niger

B076 Vaux's Swift
Chaetura vauxi

B077 White-throated Swift
Aeronautes saxatalis

B078 Black-chinned Hummingbird
Archilochus alexandri

B079 Anna's Hummingbird
Calypte anna

B080 Allen's Hummingbird
Selasphorus sasin

B081 Rufous Hummingbird
Selasphorus rufus

B082 Calliope Hummingbird
Stellula calliope

B083 Belted Kingfisher
Megaceryle alcyon

B084 Common Flicker
Colaptes auratus

B085 Pileated Woodpecker
Dryocopus pileatus

B086 Acorn Woodpecker
Melanerpes formicivorous

B087 Lewis' Woodpecker
Melanerpes lewis

B088 Yellow-bellied Sapsucker
Sphyrapicus varius

B089 Williamson's Sapsucker
Sphyrapicus thyroideus

B090 Hairy Woodpecker
Picoides villosus

B091 Downy Woodpecker
Picoides pubescens

B092 Nuttall's Woodpecker
Picoides nuttallii

B093 White-headed Woodpecker
Picoides albolarvatus

B094 Black-backed Three-toed Woodpecker
Picoides arcticus

B095 Western Kingbird
Tyrannus verticalis

B096 Ash-throated Flycatcher
Myiarchus cinerascens

B097 Black Phoebe
Sayornis nigricans

B098 Say's Phoebe
Sayornis saya

B099 Willow Flycatcher
Empidonax traillii

B100 Hammond's Flycatcher
Empidonax hammondii

B101 Dusky Flycatcher
Empidonax oberholseri

B102 Western Flycatcher
Empidonax difficilis

B103 Western Wood Pewee
Contopus sordidulus

B104 Olive-sided Flycatcher
Nuttallornis borealis

B105 Horned Lark
Eremophila alpestris

B106 Violet-green Swallow
Tachycineta thalassina

B107 Tree Swallow
Iridoprocne bicolor

B108 Rough-winged Swallow
Stelgidopteryx ruficollis

B109 Barn Swallow
Hirundo rustica

B110 Cliff Swallow
Petrochelidon pyrrhonota

B111 Steller's Jay
Cyanocitta stelleri

B112 Scrub Jay
Aphelocoma coerulescens

B113 Black-billed Magpie
Pica pica

B114 Yellow-billed Magpie
Pica nuttalli

B115 Common Raven
Corvus corax

B116 Common Crow
Corvus brachyrhynchos

B117 Piñon Jay
Gymnorhinus cyanocephalus

B118 Clark's Nutcracker
Nucifraga columbiana

B119 Mountain Chickadee
Parus gambeli

B120 Chestnut-backed Chickadee
Parus rufescens

B121 Plain Titmouse
Parus inornatus

B122 Bushtit
Psaltriparus minimus

B123 White-breasted Nuthatch
Sitta carolinensis

B124 Red-breasted Nuthatch
Sitta canadensis

B125 Pygmy Nuthatch
Sitta pygmaea

B126 Brown Creeper
Certhia familiaris

B127 Wrentit
Chamaea fasciata

B128 Dipper
Cinclus mexicanus

B129 Winter Wren
Troglodytes troglodytes

B130 House Wren
Troglodytes aedon

B131 Bewick's Wren
Thryomanes bewickii

B132 Long-billed Marsh Wren
Cistothorus palustris

B133 Cañon Wren
Catherpes mexicanus

B134 Rock Wren
Salpinctes obsoletus

B135 Mockingbird
Mimus polyglottos

B136 California Thrasher
Toxostoma redivivum

B137 American Robin
Turdus migratorius

B138 Varied Thrush
Ixoreus naevius

B139 Hermit Thrush
Catharus guttata

B140 Swainson's Thrush
Catharus ustulata

B141 Western Bluebird
Sialia mexicana

B142 Mountain Bluebird
Sialia currucoides

B143 Townsend's Solitaire
Myadestes townsendi

B144 Blue-gray Gnatcatcher
Polioptila caerulea

B145 Golden-crowned Kinglet
Regulus satrapa

B146 Ruby-crowned Kinglet
Regulus calendula

B147 Water Pipit
Anthus spinoletta

B148 Cedar Waxwing
Bombycilla cedrorum

B149 Phainopepla
Phainopepla nitens

B150 Loggerhead Shrike
Lanius ludovicianus

B151 Starling
Sturnus vulgaris

B152 Hutton's Vireo
Vireo huttoni

B153 Bell's Vireo
Vireo bellii

B154 Solitary Vireo
Vireo solitarius

B155 Warbling Vireo
Vireo gilvus

B156 Orange-crowned Warbler
Vermivora celata

B157 Nashville Warbler
Vermivora ruficapilla

B158 Yellow Warbler
Dendroica petechia

B159 Yellow-rumped Warbler
Dendroica coronata

B160 Black-throated Gray Warbler
Dendroica nigrescens

B161 Townsend's Warbler
Dendroica townsendi

B162 Hermit Warbler
Dendroica occidentalis

B163 MacGillivray's Warbler
Oporornis tolmiei

B164 Common Yellowthroat
Geothlypis trichas

B165 Yellow-breasted Chat
Icteria virens

B166 Wilson's Warbler
Wilsonia pusilla

B167 House Sparrow
Passer domesticus

B168 Western Meadowlark
Sturnella neglecta

B169 Yellow-headed Blackbird
Xanthocephalus xanthocephalus

B170 Red-winged Blackbird
Agelaius phoeniceus

B171 Tricolored Blackbird
[illegible]

B172 Northern Oriole
Icterus galbula

B173 Brewer's Blackbird
Euphagus cyanocephalus

B174 Brown-headed Cowbird
Molothrus ater

B175 Western Tanager
Piranga ludoviciana

B176 Black-headed Grosbeak
Pheucticus melanocephalus

B177 Blue Grosbeak
Guiraca caerulea

B178 Lazuli Bunting
Passerina amoena

B179 Evening Grosbeak
Hesperiphona vespertina

B180 Purple Finch
Carpodacus purpureus

B181 Cassin's Finch
Carpodacus cassinii

B182 House Finch
Carpodacus mexicanus

B183 Pine Grosbeak
Pinicola enucleator

B184 Gray-crowned Rosy Finch
Leucosticte tephrocotis

B185 Pine Siskin
Carduelis pinus

B186 American Goldfinch
Carduelis tristis

B187 Lesser Goldfinch
Carduelis psaltria

B188 Lawrence's Goldfinch
Carduelis lawrencei

B189 Red Crossbill
Loxia curvirostra

B190 Green-tailed Towhee
Pipilo chlorurus

B191 Rufous-sided Towhee
Pipilo erythrophthalmus

B192 Brown Towhee
Pipilo fuscus

B193 Savannah Sparrow
Passerculus sandwichensis

B194 Grasshopper Sparrow
Ammodramus savannarum

B195 Vesper Sparrow
Pooecetes gramineus

B196 Lark Sparrow
Chondestes grammacus

B197 Rufous-crowned Sparrow
Aimophila ruficeps

B198 Black-throated Sparrow
Amphispiza bilineata

B199 Sage Sparrow
Amphispiza belli

B200 Dark-eyed Junco
Junco hyemalis

B201 Chipping Sparrow
Spizella passerina

B202 Brewer's Sparrow
Spizella breweri

B203 Black-chinned Sparrow
Spizella atrogularis

B204 White-crowned Sparrow
Zonotrichia leucophrys

B205 Golden-crowned Sparrow
Zonotrichia atricapilla

B206 Fox Sparrow
Passerella iliaca

B207 Lincoln's Sparrow
Melospiza lincolnii

B208 Song Sparrow
Melospiza melodia

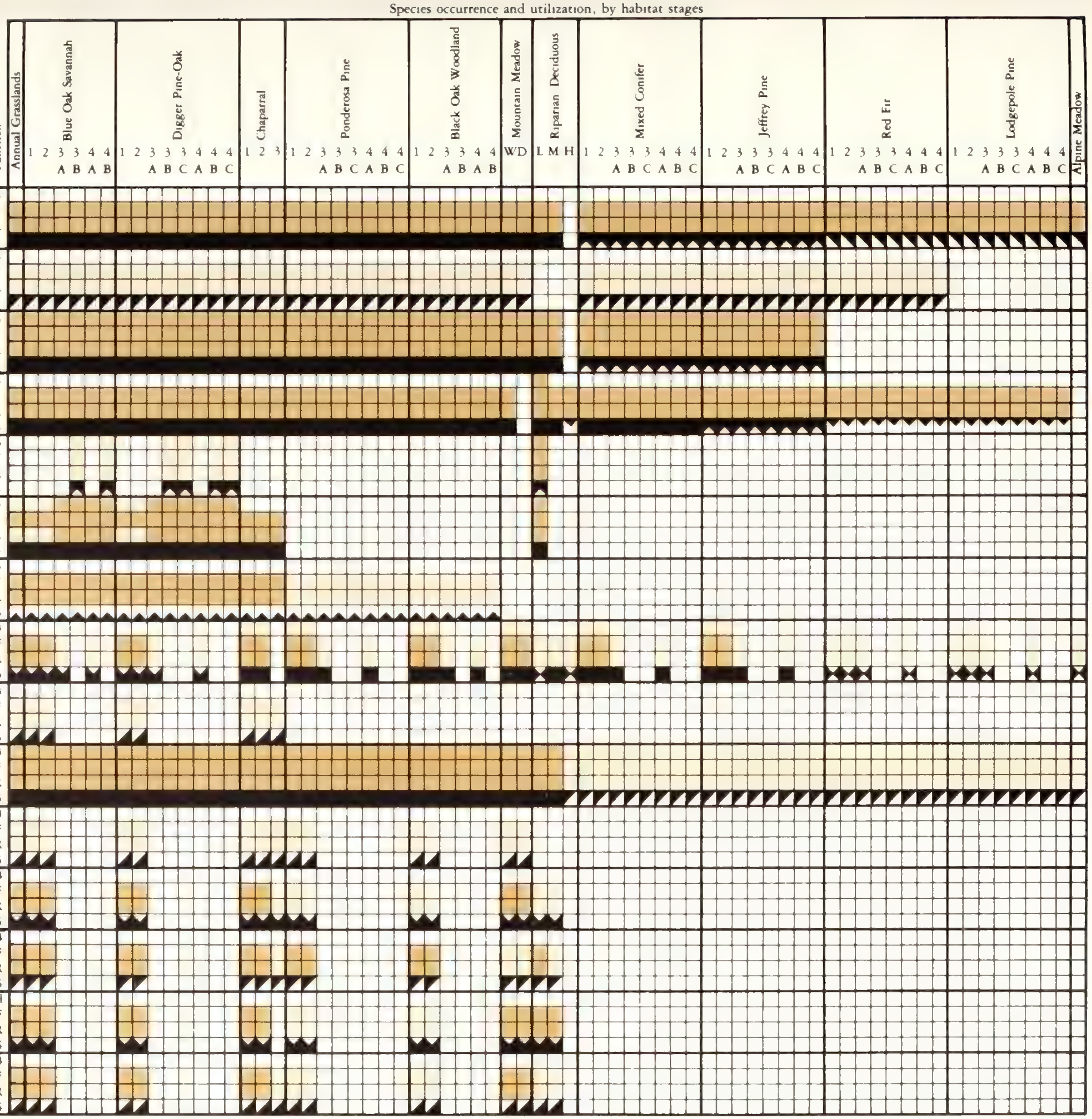
LEGEND

- Optimum Habitat (1)
- Suitable Habitat (2)
- Marginal Habitat (3)
- Spring
- Summer
- Fall
- Winter

For key to this matrix, see *figure 2*

Species occurrence and utilization, by habitat stages

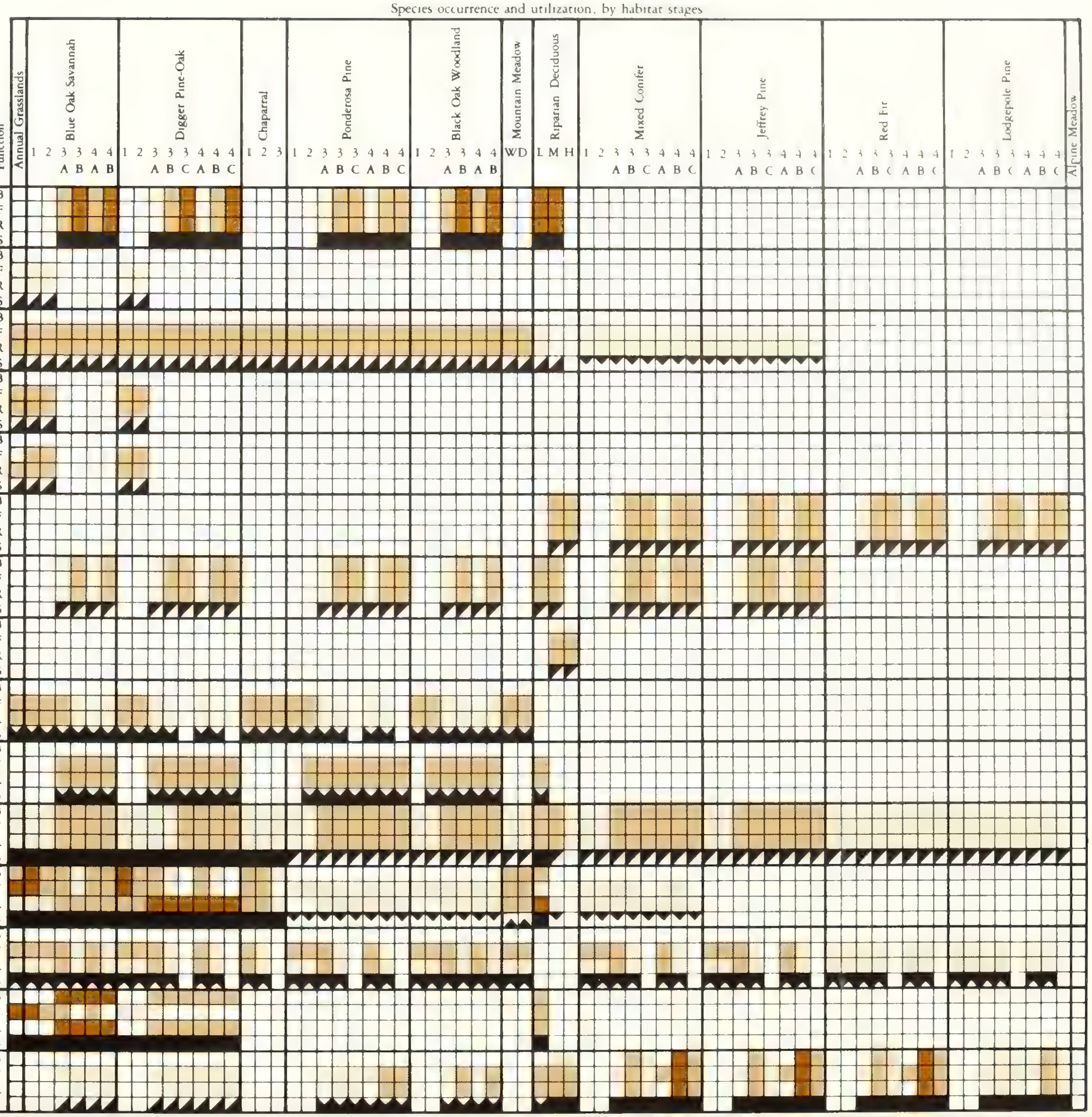
Code	Species	Special Habitat Requirements	Page	Function
B001	Eared Grebe	Ponds, lakes, or large pools in streams or rivers	93	B F R S
B002	Western Grebe	Lakes	94	B F R S
B003	Pied-billed Grebe	Marsh; pond, lake, or pool in river or stream	95	B F R S
B004	Great Blue Heron	Ponds, lakes, streams, rivers, marshes, or wet meadows	96	B F R S
B005	Green Heron	Ponds, lakes, or slow-moving streams or rivers with tree border	97	B F R S
B006	Black-crowned Night Heron	Ponds, lakes, marshes, slow streams or rivers with pools	98	B F R S
B007	Whistling Swan	Lakes—shallow and productive	99	B F R S
B008	Canada Goose	Lakes	100	B F R S
B009	Snow Goose	Lakes	101	B F R S
B010	Mallard	Ponds, lakes, slow-moving streams or rivers	102	B F R S
B011	Pintail	Ponds, lakes	103	B F R S
B012	Green-winged Teal	Ponds, lakes, or marshes	104	B F R S
B013	Cinnamon Teal	Ponds, lakes, slow-moving streams or rivers	105	B F R S
B014	American Wigeon	Ponds, lakes, or slow-moving streams or rivers	106	B F R S
B015	Northern Shoveler	Ponds, lakes, or slow-moving streams or rivers	107	B F R S



LEGEND
Optimum Habitat (1)
Suitable Habitat (2)
Marginal Habitat (3)
Spring
Summer
Fall
Winter

For key to this matrix, see *figure 2*

Code	Species	Special Habitat Requirements	Page	Function
B016	Wood Duck	Ponds, slow-moving streams or rivers, nest cavities, oaks	108	B F R S
B017	Redhead	Lakes with deep water	109	B F R S
B018	Ring-necked Duck	Ponds, lakes	110	B F R S
B019	Canvasback	Lakes	111	B F R S
B020	Lesser Scaup	Ponds, lakes	112	B F R S
B021	Barrow's Goldeneye	Ponds, lakes, nest cavities (see narrative on breeding)	113	B F R S
B022	Bufflehead	Ponds, lakes, slow-moving streams, nest cavities	114	B F R S
B023	Harlequin Duck	Swift streams or rivers (see narrative on breeding)	115	B F R S
B024	Ruddy Duck	Ponds, lakes	116	B F R S
B025	Hooded Merganser	Ponds, lakes, slow-moving streams or rivers	117	B F R S
B026	Common Merganser	Ponds, lakes, slow-moving streams or rivers	118	B F R S
B027	Turkey Vulture	Open terrain for foraging	119	B F R S
B028	California Condor **ENDANGERED**	Open terrain for foraging; large trees or cliffs for roosting	120	B F R S
B029	White-tailed Kite	Dense-canopied trees for nesting	121	B F R S
B030	Goshawk **SENSITIVE**	Water probably needed on breeding territory	122	B F R S



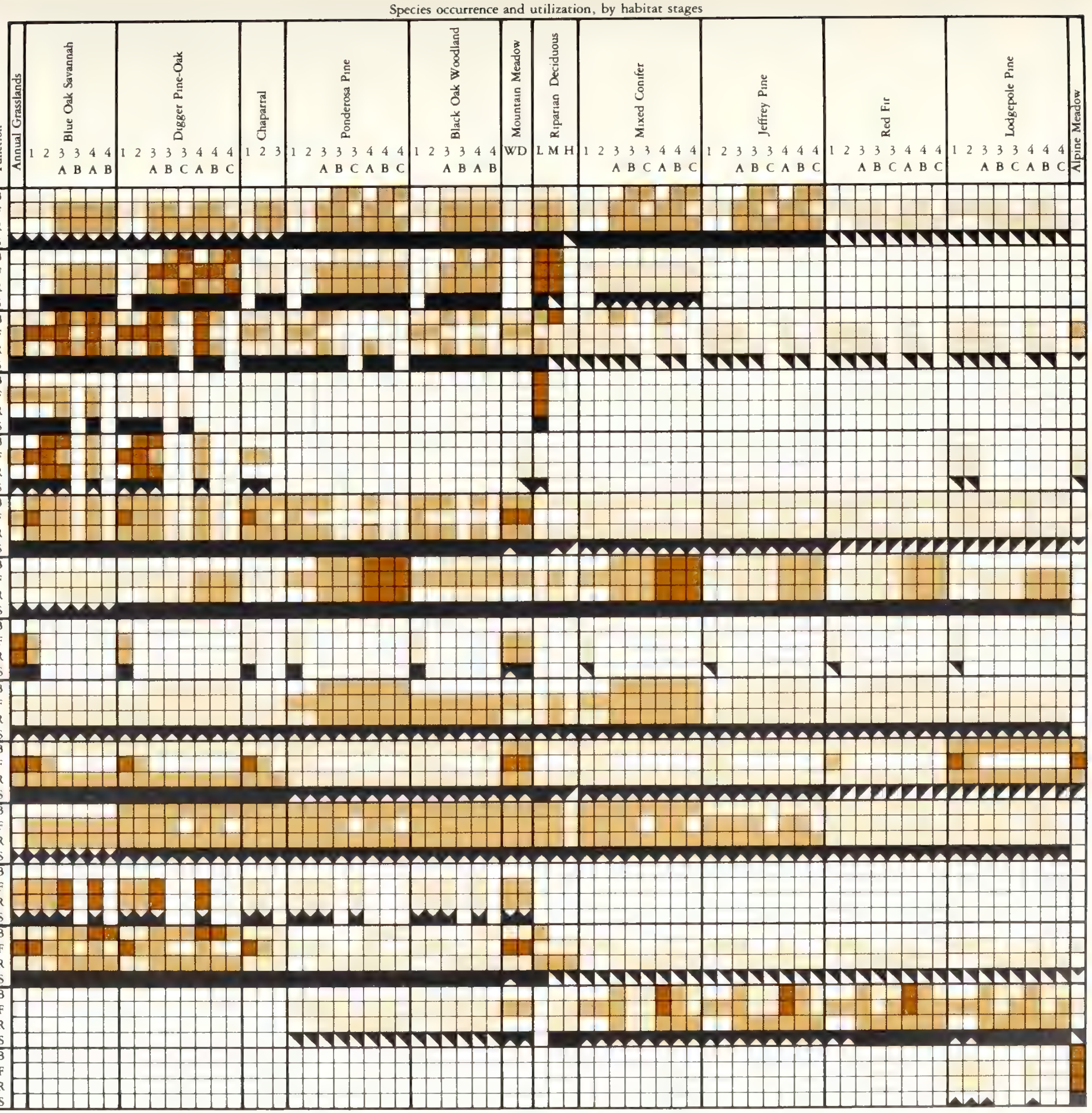
LEGEND

- Optimum Habitat (1)
- Suitable Habitat (2)
- Marginal Habitat (3)
- Spring
- Summer
- Fall
- Winter

For key to this matrix, see *figure 2*.

Species occurrence and utilization, by habitat stages

Code	Species	Special Habitat Requirements	Page	Function
B031	Sharp-shinned Hawk	Trees/shrubs	123	B F R S
B032	Cooper's Hawk	Trees/shrubs or trees/grass-forbs; water probably needed nearby for breeding	124	B F R S
B033	Red-tailed Hawk	Large trees or cliff for nesting and roosting; large openings for foraging	125	B F R S
B034	Red-shouldered Hawk	Large tracts of riparian deciduous woodland for breeding	126	B F R S
B035	Swainson's Hawk		127	B F R S
B036	Golden Eagle SENSITIVE	Cliffs or scattered large trees	128	B F R S
B037	Bald Eagle ENDANGERED	Large lake, stream or river, large trees for nesting; low human disturbance	129	B F R S
B038	Marsh Hawk		130	B F R S
B039	Osprey SENSITIVE	Lakes, rivers for feeding, snags, large trees, or cliffs for nesting	131	B F R S
B040	Prairie Falcon SENSITIVE	Open terrain for foraging, cliffs for nesting	132	B F R S
B041	Peregrine Falcon ENDANGERED	Cliffs for nesting and perching; nearby lake or river	133	B F R S
B042	Merlin		134	B F R S
B043	American Kestrel	Nest cavities in trees or earthen bank; elevated perches; open terrain	135	B F R S
B044	Blue Grouse	Medium to large forest openings; shrubs/grass-forbs	136	B F R S
B045	White-tailed Ptarmigan	Rock outcrops; probably shrubs/grass-forbs	137	B F R S



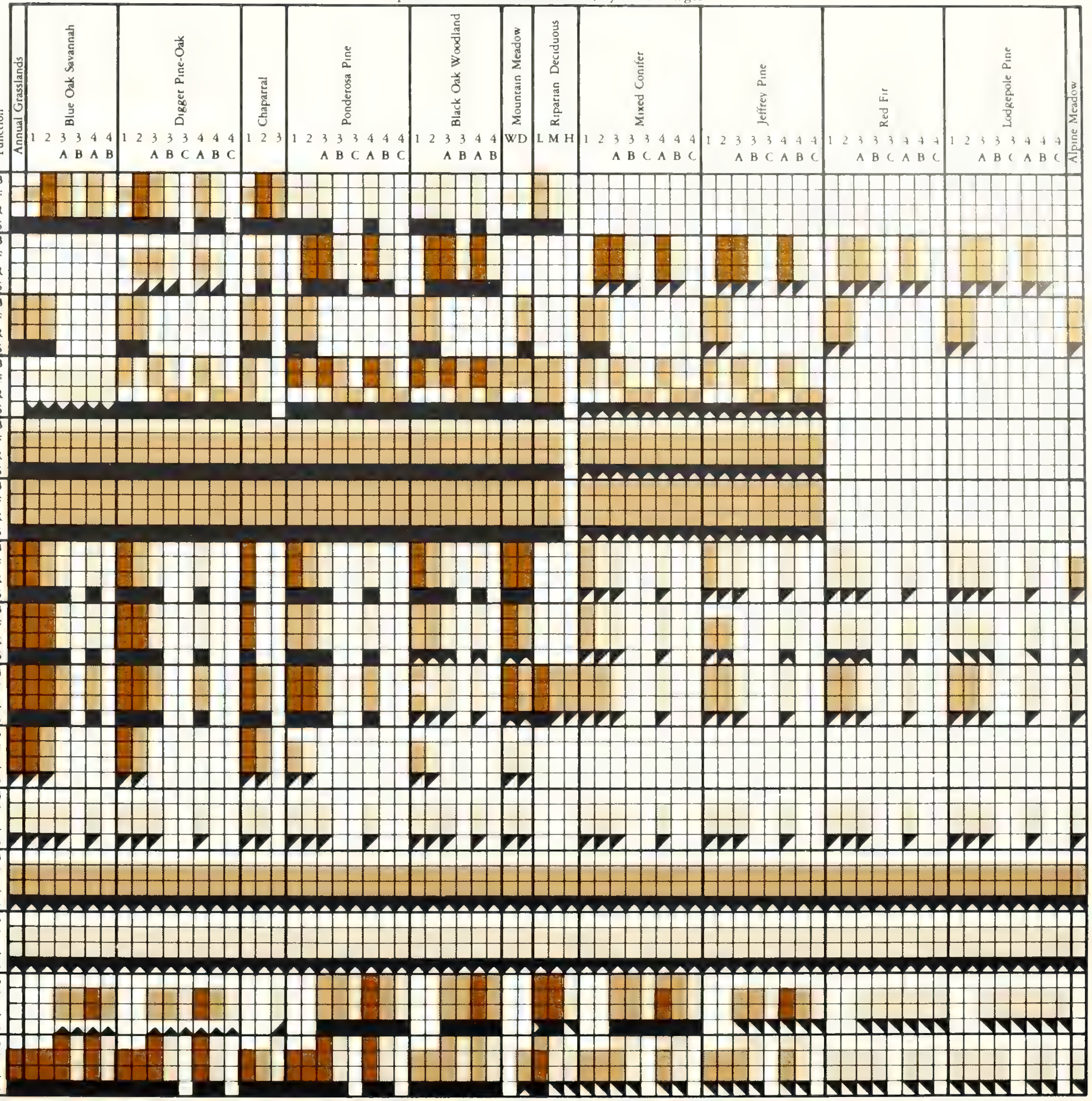
LEGEND

Optimum Habitat (1)
Suitable Habitat (2)
Marginal Habitat (3)
Spring
Summer
Fall
Winter

For key to this matrix, see *figure 2*.

Code	Species	Special Habitat Requirements	Page
B046	California Quail	Shrubs/grass-forbs; water in dry season	138
B047	Mountain Quail	Shrubs/grass-forbs, water in breeding season	139
B048	Chukar	Rock outcrops or talus; water	140
B049	Turkey	Water; trees/grass-forbs	141
B050	Virginia Rail	Marshes; open water	142
B051	American Coot	Ponds, lakes, slow-moving streams or rivers	143
B052	Killdeer	Open terrain, rarely far from ponds, lakes, streams, or rivers	144
B053	Common Snipe	Wet margins of ponds, lakes, streams, rivers, or marshes	145
B054	Spotted Sandpiper	Gravelly or sandy margins of ponds, lakes, streams, or rivers	146
B055	American Avocet	Open terrain; pond or lake margins	147
B056	Wilson's Phalarope	Open terrain; pond, lake, or marsh edges	148
B057	California Gull	Lakes, rivers	149
B058	Ring-billed Gull	Lakes, rivers	150
B059	Band-tailed Pigeon	Large trees; nearby water	151
B060	Mourning Dove	Trees for nesting; nearby water	152

Species occurrence and utilization, by habitat stages



LEGEND

- Optimum Habitat (1)
- Suitable Habitat (2)
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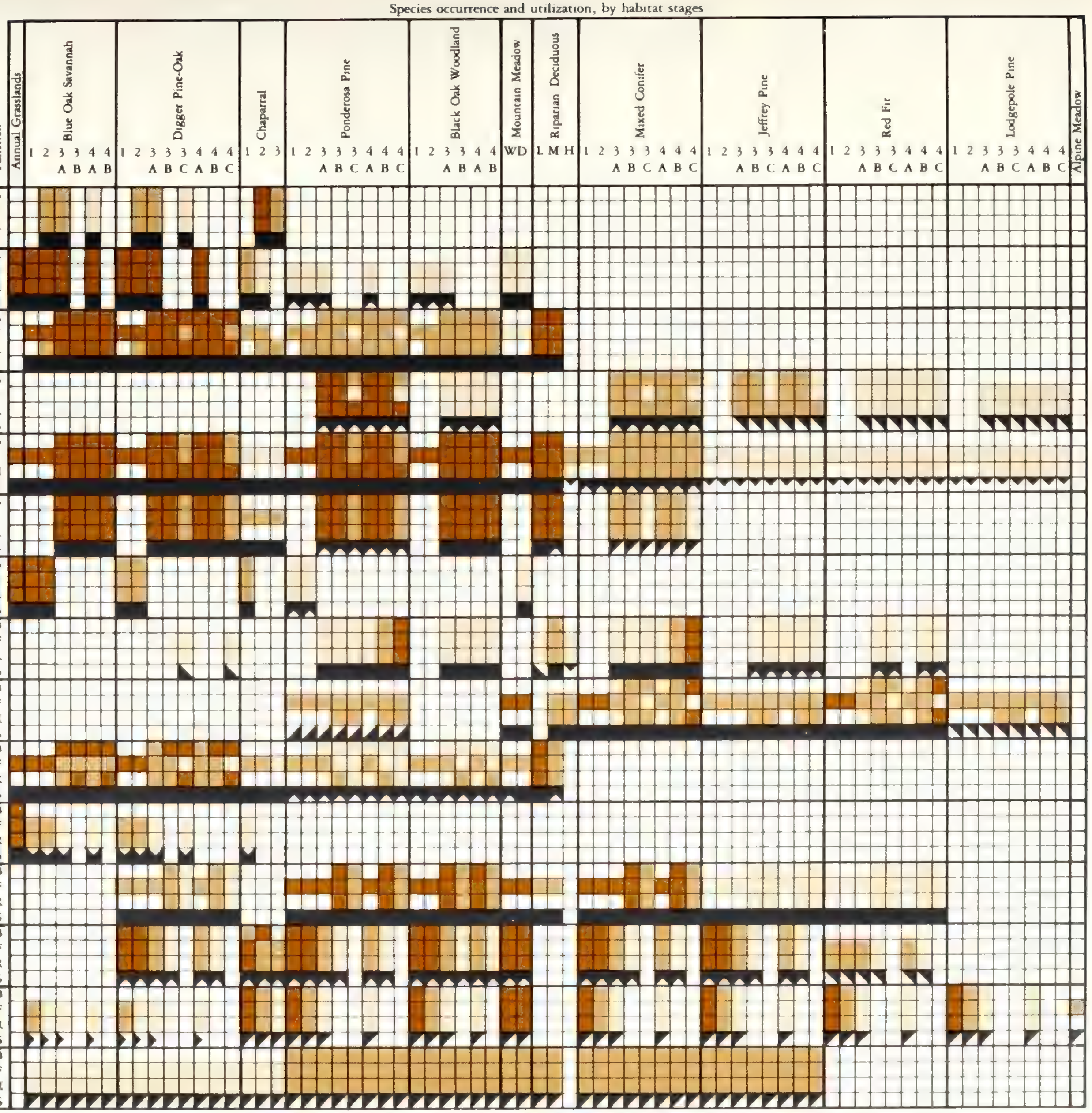
- Spring
- Summer
- Fall
- Winter

For key to this matrix, see *figure 2*.

Code	Species	Special Habitat Requirements	Page	Function
B061	Roadrunner	Nearby water	153	B F R S
B062	Barn Owl	Cliffs, crevices, or old buildings for nesting	154	B F R S
B063	Screech Owl	Oaks; nest cavities	155	B F R S
B064	Flammulated Owl	Yellow pines or black oaks in nesting habitat; nest cavities	156	B F R S
B065	Great Horned Owl	Large openings for foraging	157	B F R S
B066	Pygmy Owl	Nest cavities	158	B F R S
B067	Burrowing Owl	Ground burrows	159	B F R S
B068	Spotted Owl SENSITIVE	Water probably needed, large trees	160	B F R S
B069	Great Gray Owl	Trees/grass-forbs (see narrative on distribution)	161	B F R S
B070	Long-eared Owl	Trees/grass-forbs; riparian habitat nearby	162	B F R S
B071	Short-eared Owl	Annual grassland or marsh	163	B F R S
B072	Saw-whet Owl	Trees/grass-forbs, nest cavities	164	B F R S
B073	Poor-will	Trees/shrubs; rock outcrops or logs for nesting cover	165	B F R S
B074	Common Nighthawk	Open terrain for feeding	166	B F R S
B075	Black Swift	Cliffs for nesting	167	B F R S



LEGEND

- Optimum Habitat (1)
- Suitable Habitat (2)
- Marginal Habitat (3)
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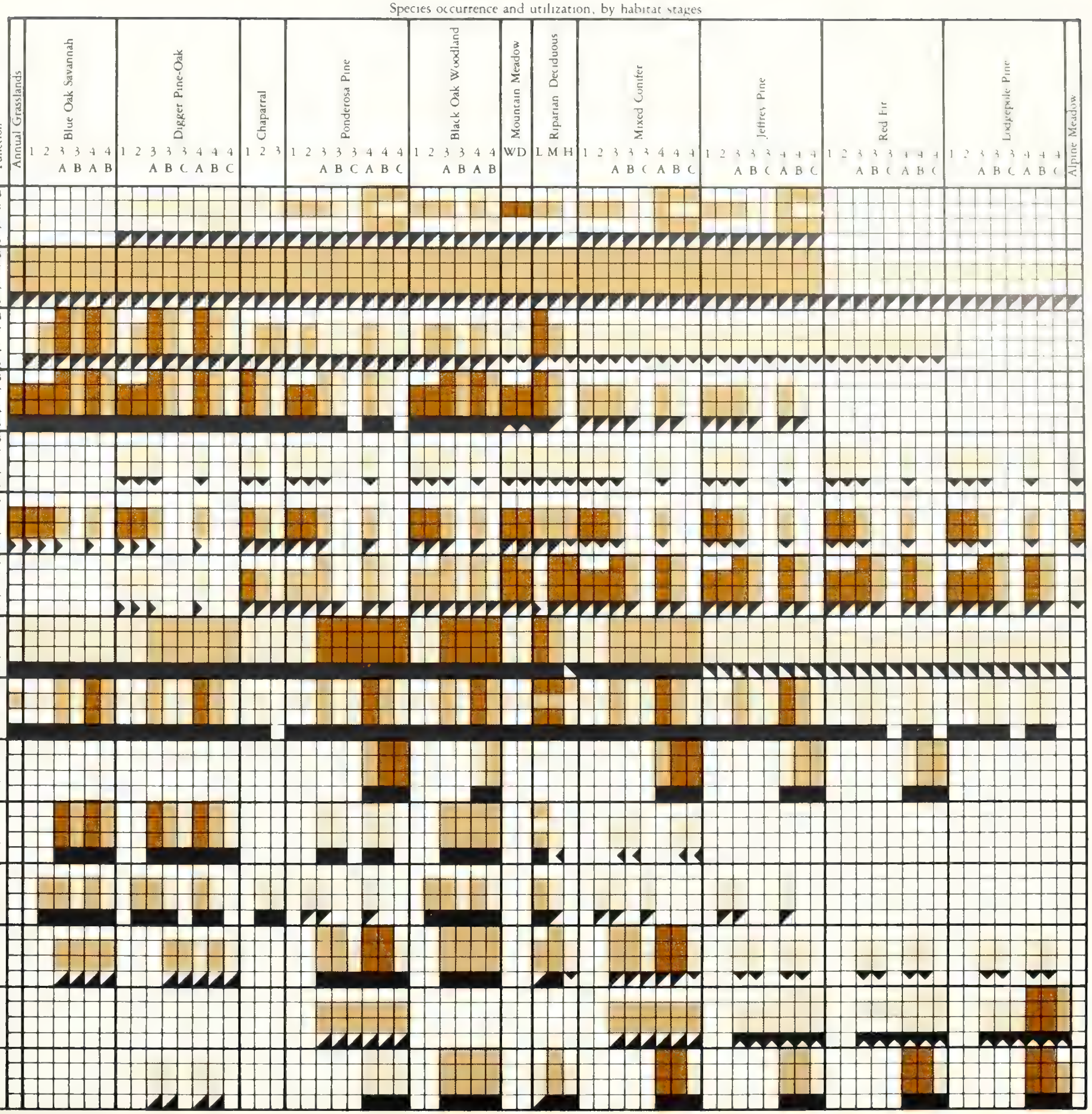
- Winter

For key to this matrix, see *figure 2*

Code	Species	Special Habitat Requirements	Page	Function
[illegible]	[illegible]	Hollow stubs or snags for nesting	168	B F R S
[illegible]	White-throated Swift	Cliffs for nesting	169	B F R S
[illegible]	Black-chinned Hummingbird	Nectar source, water	170	B F R S
[illegible]	Anna's Hummingbird	Nectar source, small, medium or large openings, water	171	B F R S
B080	Allen's Hummingbird	Nectar source (see narrative on identification)	172	B F R S
B081	Rufous Hummingbird	Nectar source	173	B F R S
B082	Calliope Hummingbird	Nectar source, water	174	B F R S
B083	Belted Kingfisher	Earthen banks for nesting; pond, lake, stream, or river for feeding	175	B F R S
B084	Common Flicker	Snags or trees with soft heartwood	176	B F R S
B085	Pileated Woodpecker	Large snags; low human disturbance	177	B F R S
B086	Acorn Woodpecker	Oaks, large trees	178	B F R S
B087	Lewis' Woodpecker	Oaks in fall and winter	179	B F R S
B088	Yellow-bellied Sapsucker	Snags or trees with soft heartwood for cavity excavation	180	B F R S
B089	Williamson's Sapsucker	Snags	181	B F R S
B090	Hairy Woodpecker	Snags	182	B F R S

Species occurrence and utilization, by habitat stages

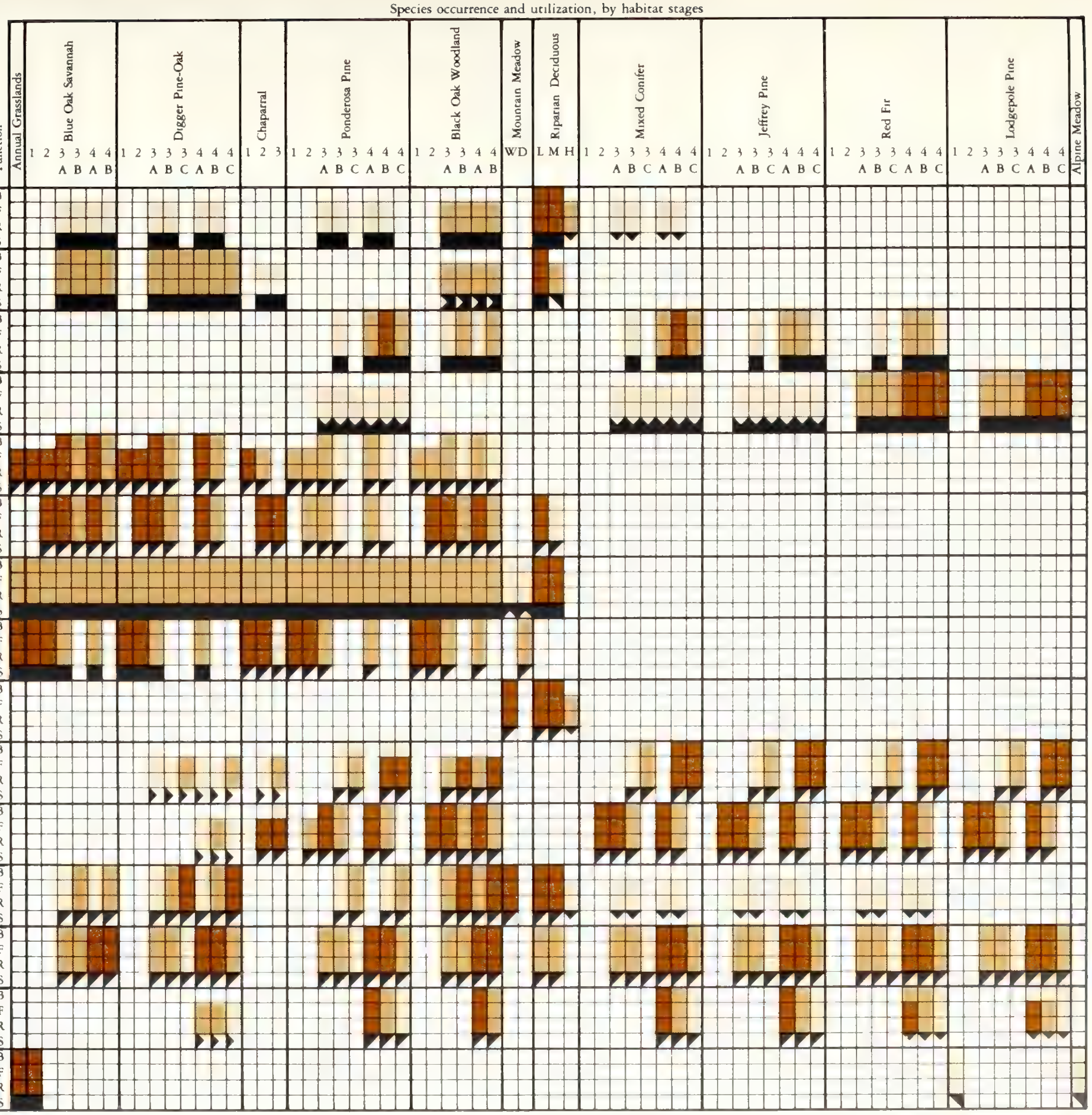


LEGEND
- Optimum Habitat (1)
- Suitable Habitat (2)
- Marginal Habitat (3)
- Spring
- Summer
- Fall
- Winter

For key to this matrix, see *figure 2*.

Species occurrence and utilization, by habitat stages

Code	Species	Special Habitat Requirements	Page	Function
B091	Downy Woodpecker	Snags or trees with soft heartwood	183	B F R S
B092	Nuttall's Woodpecker	Snags	184	B F R S
B093	White-headed Woodpecker	Snags	185	B F R S
B094	Black-backed Three-toed Woodpecker	Snags or trees with soft heartwood	186	B F R S
B095	Western Kingbird	Elevated perches	187	B F R S
B096	Ash-throated Flycatcher	Nest cavities	188	B F R S
B097	Black Phoebe	Water source, cliffs, old buildings, or bridges for nesting	189	B F R S
B098	Say's Phoebe	Crevices, old buildings, or bridges for nesting	190	B F R S
B099	Willow Flycatcher	Willow thickets	191	B F R S
B100	Hammond's Flycatcher		192	B F R S
B101	Dusky Flycatcher	Trees/shrubs	193	B F R S
B102	Western Flycatcher	Stream, spring, or seep probably needed for nesting	194	B F R S
B103	Western Wood Pewee		195	B F R S
B104	Olive-sided Flycatcher	Trees/shrubs or trees/grass-forbs	196	B F R S
B105	Horned Lark		197	B F R S



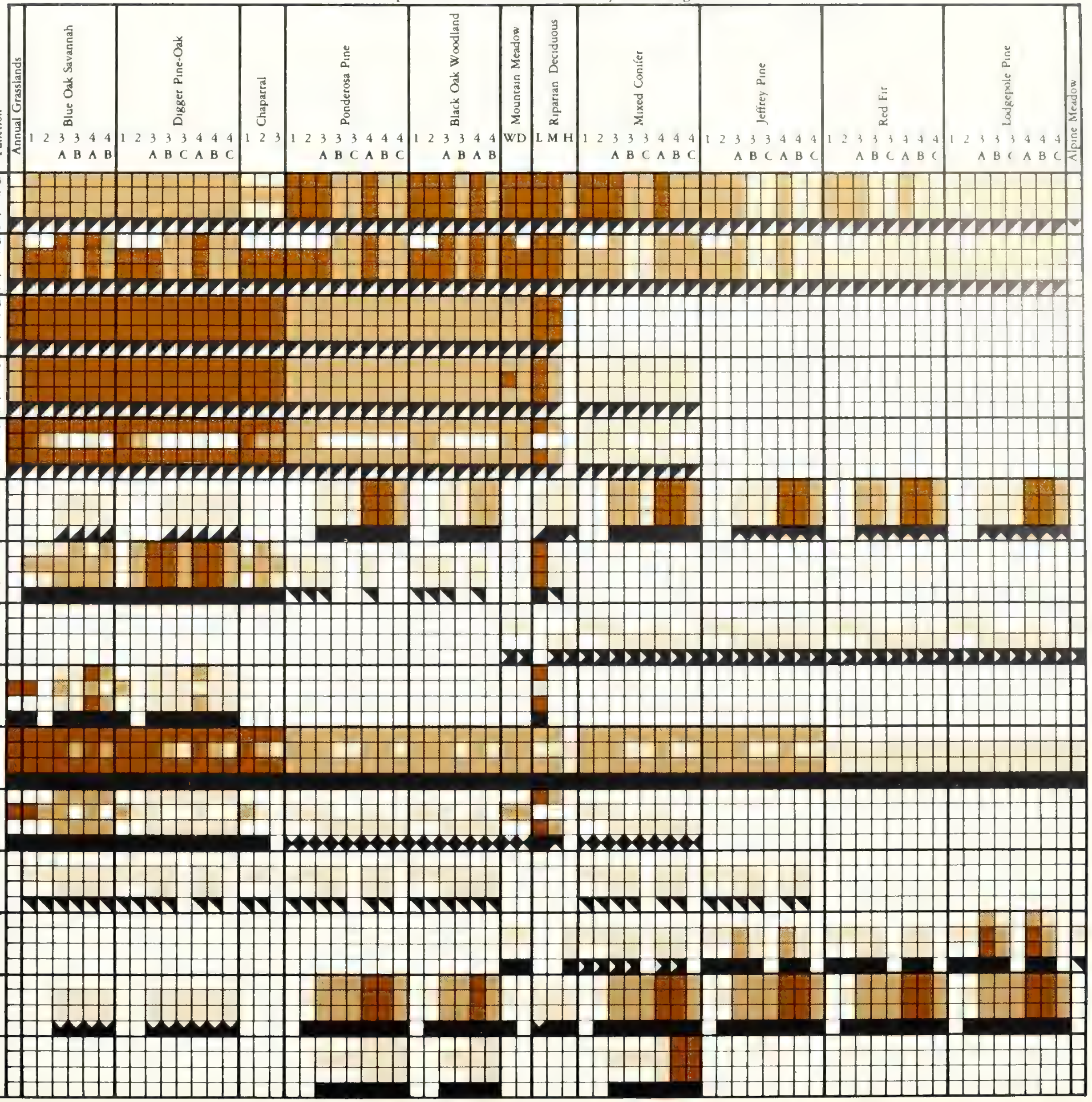
LEGEND

- Optimum Habitat (1)
- Suitable Habitat (2)
- Marginal Habitat (3)
- Spring
- Summer
- Fall
- Winter

For key to this matrix, see *figure 2*

Species occurrence and utilization, by habitat stages

Code	Species	Special Habitat Requirements	Page	Function
B[illegible]	[illegible]	Nest cavities or crevices, medium to large openings, or open terrain	198	B F R S
B[illegible]7	Tree Swallow	Nests in cavities by pond, lake, stream, river, marsh, or wet meadow	199	B F R S
B108	Rough-winged Swallow	Earthen bank	200	B F R S
B109	Barn Swallow	Cliffs, old buildings, or bridges for nesting, nearby water for mud gathering	201	B F R S
B110	Cliff Swallow	Cliffs, old buildings, or bridges for nesting; nearby water for mud-gathering	202	B F R S
B111	Steller's Jay		203	B F R S
B112	Scrub Jay	Oaks or cultivated nut trees	204	B F R S
B113	Black-billed Magpie	Water in dry season; openings	205	B F R S
B114	Yellow-billed Magpie	Open terrain; trees; water in dry season	206	B F R S
B115	Common Raven	Large openings or open terrain; cliffs or trees for nesting	207	B F R S
B116	Common Crow	Large openings or open terrain; trees for nesting	208	B F R S
B117	Piñon Jay	Openings	209	B F R S
B118	Clark's Nutcracker	Pines	210	B F R S
B119	Mountain Chickadee	Nest cavities	211	B F R S
B120	Chestnut-backed Chickadee	Nest cavities	212	B F R S



LEGEND
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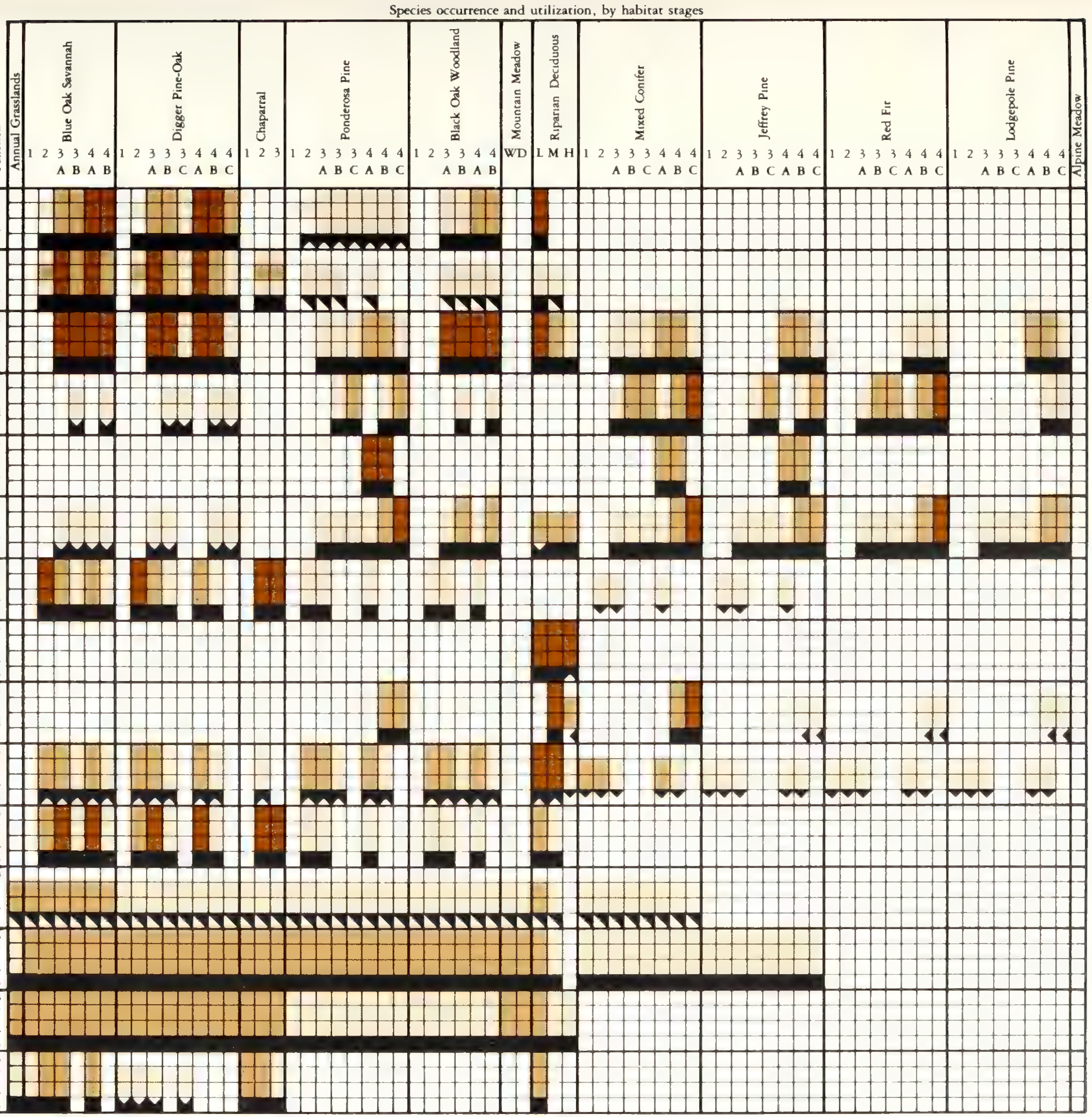
For key to this matrix, see *figure 2*.

Code	Species	Special Habitat Requirements	Page	Function
B121	Plain Titmouse	Oaks; nest cavities	213	B F R S
B122	Bushtit	Oaks; trees/shrubs	214	B F R S
B123	White-breasted Nuthatch	Nest cavities	215	B F R S
B124	Red-breasted Nuthatch	Snags or nest cavities	216	B F R S
B125	Pygmy Nuthatch	Pines, snags or nest cavities	217	B F R S
B126	Brown Creeper		218	B F R S
B127	Wrentit	Dense shrubs	219	B F R S
B128	Dipper	Clear, permanent streams or rivers	220	B F R S
B129	Winter Wren	Litter, logs in dense tangles, nest cavities	221	B F R S
B130	House Wren	Nest cavities; trees/shrubs	222	B F R S
B131	Bewick's Wren	Natural tree cavity or rock crevice for nesting; trees/shrubs	223	B F R S
B132	Long-billed Marsh Wren	Marsh	224	B F R S
B133	Cañon Wren	Small cliffs, talus, or rock outcrops	225	B F R S
B134	Rock Wren	Talus, rock outcrops	226	B F R S
B135	Mockingbird	Trees/shrubs	227	B F R S

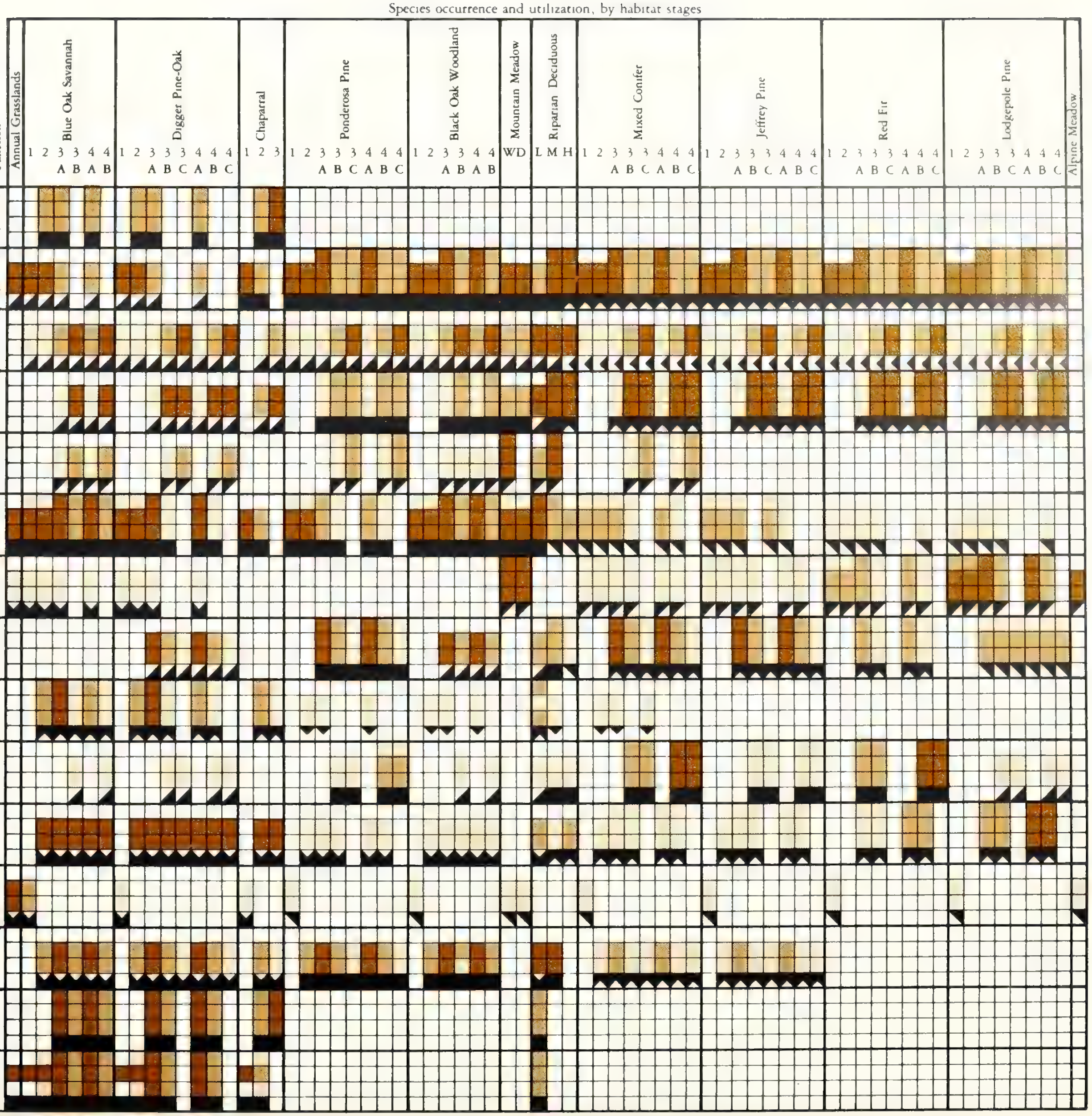


LEGEND
Optimum Habitat (1)
Suitable Habitat (2)
Marginal Habitat (3)
Spring
Summer
Fall
W[illegible]

For key to this matrix, see *figure 2*

Species occurrence and utilization, by habitat stages

[illegible]	[illegible]	Special Habitat Requirements	Page	Function
[illegible]	[illegible] Thrasher	Dense shrubs	228	B F R S
B13[illegible]	American Robin	Water (for mud in nest building); openings	229	B F R S
B138	Varied Thrush		230	B F R S
B139	Hermit Thrush		231	B F R S
B140	Swainson's Thrush	Trees/shrubs near water	232	B F R S
B141	Western Bluebird	Nest cavities, medium to large openings	233	B F R S
B142	Mountain Bluebird	Nest cavities; medium to large openings	234	B F R S
B143	Townsend's Solitaire		235	B F R S
B144	Blue-gray Gnatcatcher	Oaks in breeding season	236	B F R S
B145	Golden-crowned Kinglet		237	B F R S
B146	Ruby-crowned Kinglet		238	B F R S
B147	Water Pipit	Open terrain	239	B F R S
B148	Cedar Waxwing	Fruit, berries	240	B F R S
B149	Phainopepla	Trees/shrubs; berries (especially mistletoe)	241	B F R S
B150	Loggerhead Shrike	Shrubs/grass-forbs	242	B F R S



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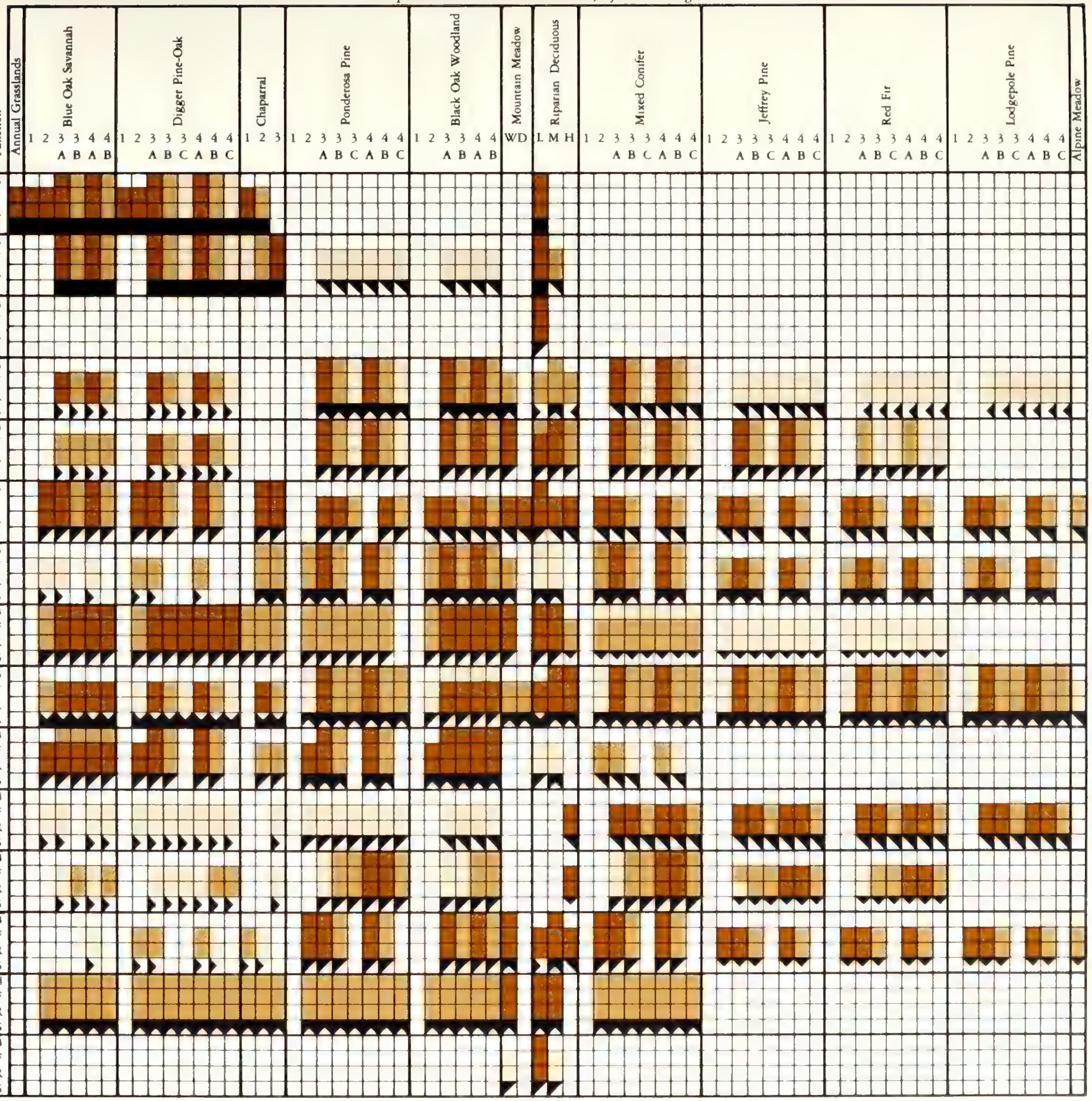
Code	Species	Special Habitat Requirements	Page	Function
B151	Starling	Nest cavities; openings or open terrain	243	B F R S
B152	Hutton's Vireo	Live oaks; trees/shrubs	244	B F R S
B153	Bell's Vireo	Dense, riparian thickets (see narrative—may be extinct in our area)	245	B F R S
B154	Solitary Vireo		246	B F R S
B155	Warbling Vireo		247	B F R S
B156	Orange-crowned Warbler	Dense shrubs for nesting	248	B F R S
B157	Nashville Warbler	Trees/shrubs	249	B F R S
B158	Yellow Warbler	Dense shrubs, nearby water for nesting	250	B F R S
B159	Yellow-rumped Warbler		251	B F R S
B160	Black-throated Gray Warbler	Oaks, trees/shrubs	252	B F R S
B161	Townsend's Warbler		253	B F R S
B162	Hermit Warbler	Large trees	254	B F R S
B163	MacGillivray's Warbler	Dense shrubs near water for nesting	255	B F R S
B164	Common Yellowthroat	Marsh or dense shrubs near water for nesting	256	B F R S
B165	Yellow-breasted Chat	Dense riparian shrubs	257	B F R S

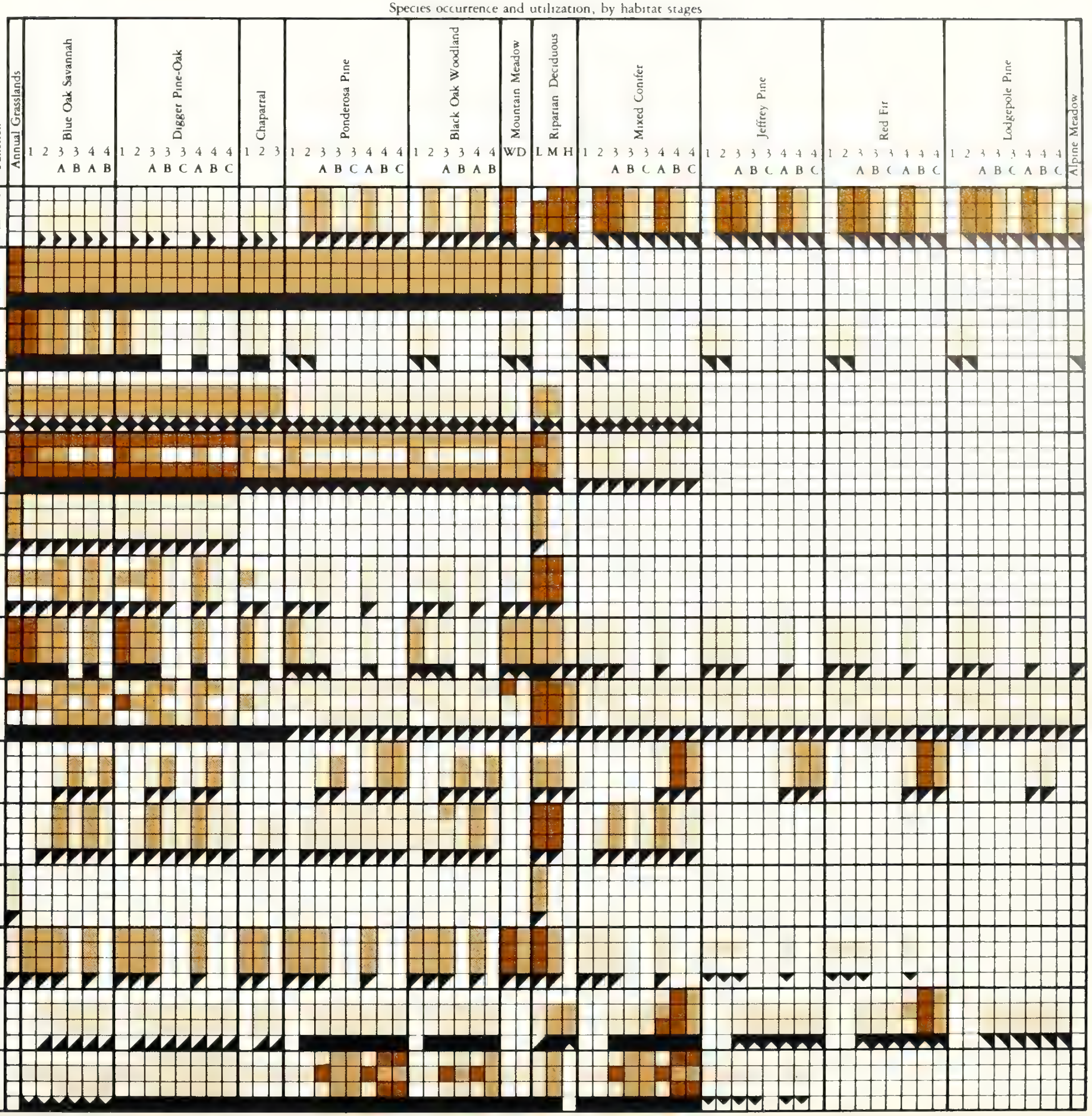
Species occurrence and utilization, by habitat stages



LEGEND
Optimum Habitat (1)
Suitable Habitat (2)
Marginal Habitat (3)
Spring
Summer
Fall
Winter

For key to this matrix, see *figure 2*

Species occurrence and utilization, by habitat stages



Code	Species	Special Habitat Requirements	Page	Function
B166	Wilson's Warbler	Dense shrubs near water for breeding	258	B F R S
B167	House Sparrow	Human habitations	259	B F R S
B168	Western Meadowlark	Open terrain	260	B F R S
B169	Yellow-headed Blackbird	Marshes for nesting; open terrain	261	B F R S
B170	Red-winged Blackbird	Marshes or shrubs near water for nesting; open terrain	262	B F R S
B171	Tricolored Blackbird	Typically marshes for nesting; open terrain	263	B F R S
B172	Northern Oriole		264	B F R S
B173	Brewer's Blackbird		265	B F R S
B174	Brown-headed Cowbird	Openings for feeding; trees for roosting	266	B F R S
B175	Western Tanager		267	B F R S
B176	Black-headed Grosbeak		268	B F R S
B177	Blue Grosbeak	Dense shrubs near water	269	B F R S
B178	Lazuli Bunting	Shrubs/grass-forbs	270	B F R S
B179	Evening Grosbeak		271	B F R S
B180	Purple Finch		272	B F R S

LEGEND

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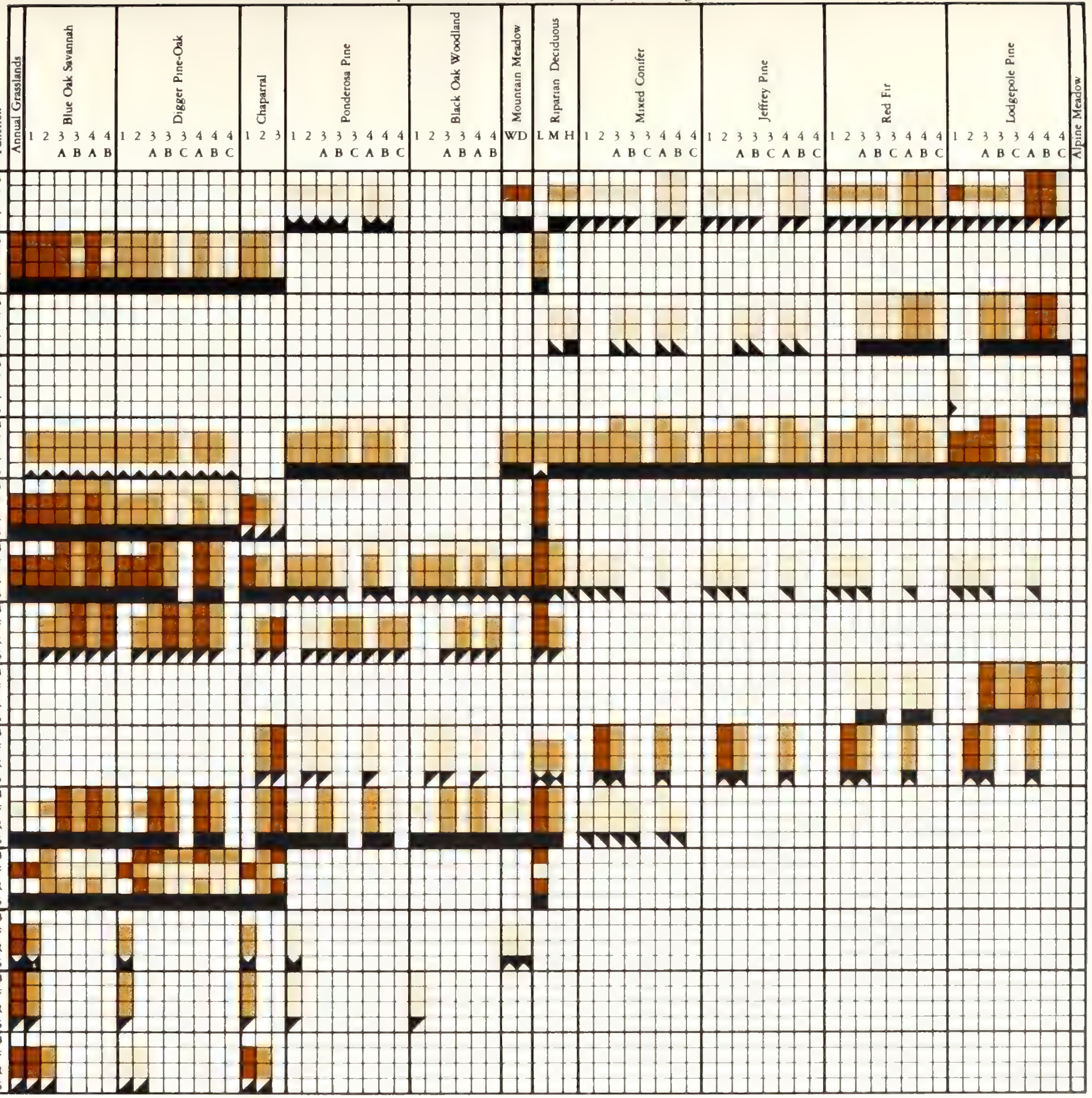
Code	Species	Special Habitat Requirements	Page	Function
B181	Cassin's Finch	Trees/grass-forbs	273	B F R S
B182	House Finch	Elevated perches	274	B F R S
B183	Pine Grosbeak	Nearby meadows or streams	275	B F R S
B184	Gray-crowned Rosy Finch	Crevices, talus, or rock outcrops for nest cover	276	B F R S
B185	Pine Siskin		277	B F R S
B186	American Goldfinch	Streams adjacent to open terrain	278	B F R S
B187	Lesser Goldfinch	Trees/shrubs, dense shrubs, water for breeding	279	B F R S
B188	Lawrence's Goldfinch	Oaks, water for breeding	280	B F R S
B189	Red Crossbill	Abundant cone crop for breeding	281	B F R S
B190	Green-tailed Towhee	Dense shrubs	282	B F R S
B191	Rufous-sided Towhee	Dense shrubs, litter	283	B F R S
B192	Brown Towhee	Dense shrubs, shrubs/grass-forbs	284	B F R S
B193	Savannah Sparrow		285	B F R S
B194	Grasshopper Sparrow		286	B F R S
B195	Vesper Sparrow		287	B F R S

Species occurrence and utilization, by habitat stages



LEGEND
Optimum Habitat (1)
Suitable Habitat (2)
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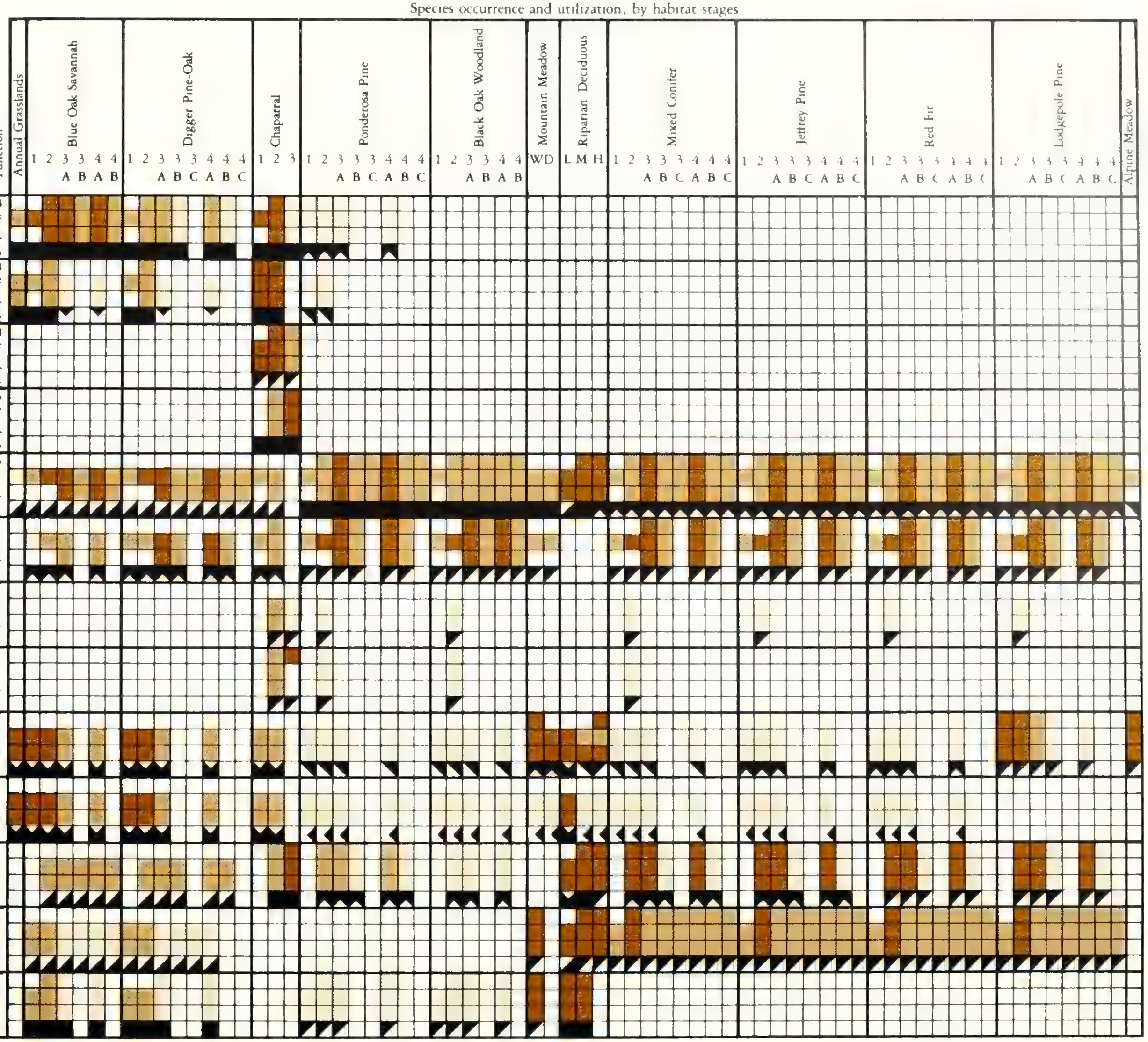
Spring
Summer
Fall
Winter

For key to this matrix, see *figure 2*

Code	Species	Special Habitat Requirements	Page	Function
B196	Lark Sparrow	Shrubs/grass-forbs	288	B F R S
B197	Rufous-crowned Sparrow	Shrubs/grass-forbs	289	B F R S
B198	Black-throated Sparrow		290	B F R S
B199	Sage Sparrow	Shrubs/grass-forbs	291	B F R S
B200	Dark-eyed Junco	Shrubs/grass-forbs	292	B F R S
B201	Chipping Sparrow		293	B F R S
B202	Brewer's Sparrow		294	B F R S
B203	Black-chinned Sparrow	Shrubs/grass-forbs	295	B F R S
B204	White-crowned Sparrow	Shrubs/grass-forbs; water for breeding	296	B F R S
B205	Golden-crowned Sparrow		297	B F R S
B206	Fox Sparrow	Dense shrubs	298	B F R S
B207	Lincoln's Sparrow	Dense shrubs; ponds, lakes, streams, rivers, or wet meadows	299	B F R S
B208	Song Sparrow	Dense shrubs; ponds, lakes, streams, rivers, or wet meadows	300	B F R S

Species occurrence and utilization, by habitat stages



Eared Grebe

B001 *(Podiceps nigricollis)*

STATUS: No official listed status. Uncommon migrant in late summer and fall; rare winter and spring visitor.

DISTRIBUTION/HABITAT: Found in all successional stages from annual grasslands through alpine meadows.

SPECIAL HABITAT REQUIREMENTS: Ponds, lakes, or large pools in streams or rivers.

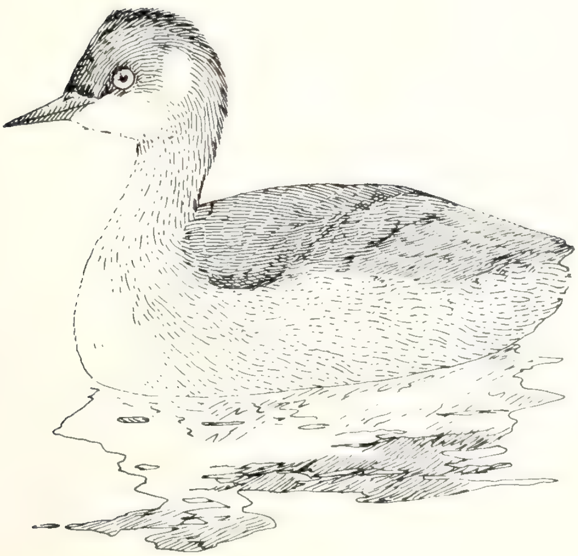
BREEDING: Does not breed on west slope of the Sierra Nevada.

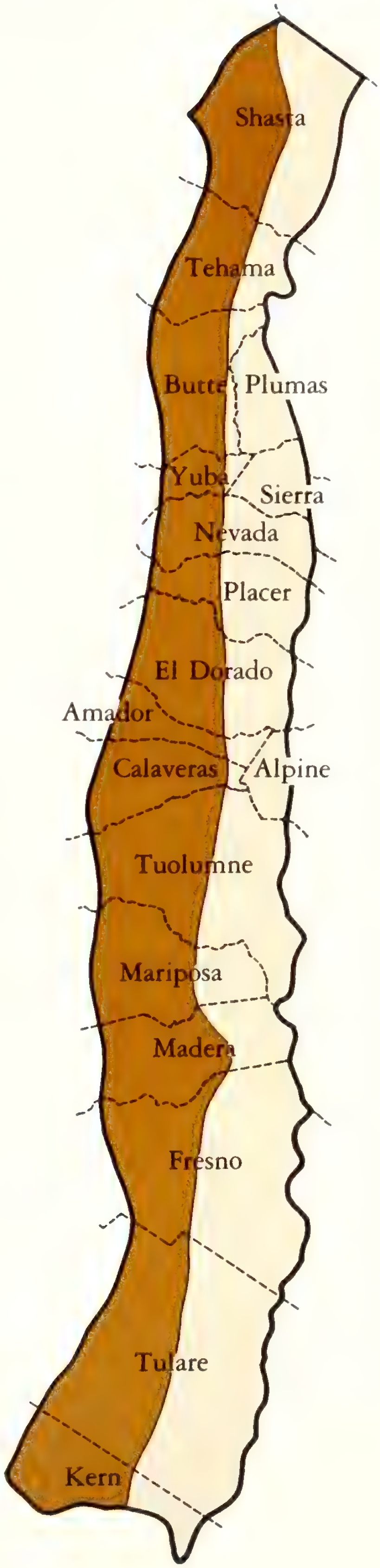
TERRITORY/HOME RANGE: No data available on home range; not territorial during nonbreeding season.

FOOD HABITS: Major food items: aquatic insects, small crustaceans, small fishes, leech eggs, mollusks, and amphibians. Forages underwater by diving. Grasps prey in bill (does not pierce); gleans land insects from surface water.

OTHER: Susceptible to biological concentration of hard pesticides in watersheds draining into its aquatic habitats.

REFERENCES: McAllister 1958, Palmer 1962.





Western Grebe

B002 *(Aechmophorus occidentalis)*

STATUS: No official listed status. On Audubon Society Blue List for 1978. Rare migrant during late spring and summer.

DISTRIBUTION/HABITAT: Found in all successional stages from annual grasslands through red fir.

SPECIAL HABITAT REQUIREMENTS: Lakes.

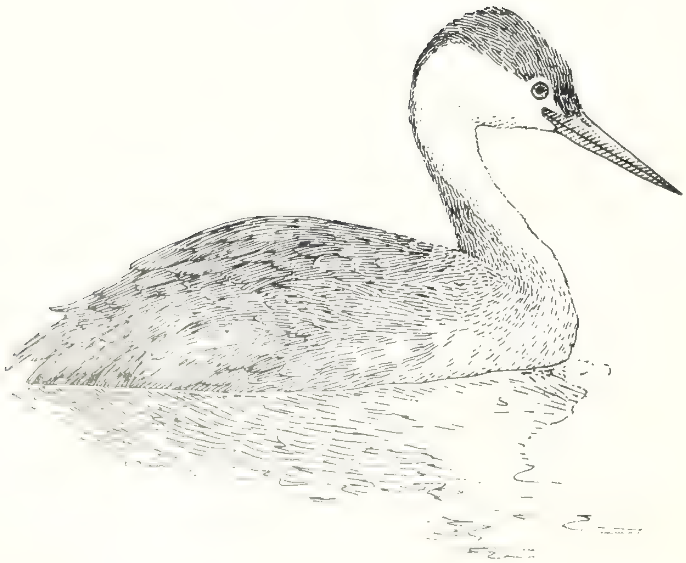
BREEDING: Does not breed on west slope of the Sierra Nevada.

TERRITORY/HOME RANGE: No data on home range. Territorial only during breeding season. When feeding, "territoriality" operates to space individuals about 200 ft (61 m) apart during breeding season (Lawrence 1950).

FOOD HABITS: Feeds mainly on small fish, also on insects underwater. Dives for prey and pierces fish with bill; some prey grasped rather than pierced.

OTHER: Susceptible to biological concentration of hard pesticides in watersheds draining into its aquatic habitats.

REFERENCES: Lawrence 1950, Palmer 1962.



Pied-billed Grebe

B003 *(Podilymbus podiceps)*

STATUS: No official listed status. Rare resident.

DISTRIBUTION/HABITAT: Found in all successional stages from annual grasslands through Jeffrey pine.

SPECIAL HABITAT REQUIREMENTS: Marsh and open water.

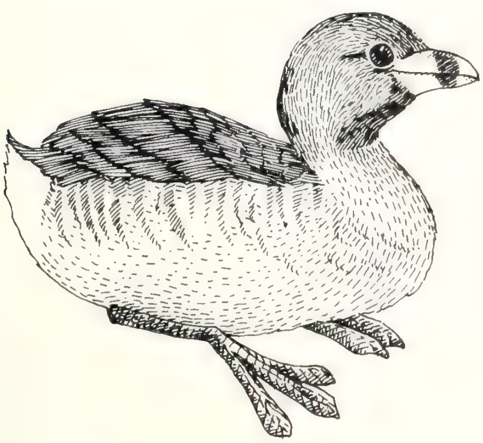
BREEDING: Breeds from mid-March to late September, with peak from early June to late July. Nest usually floating, but sometimes built up from bottom of a pond in aquatic vegetation near open water. Clutch size from 2 to 10 eggs, with 6 most common. Few nesting records from Shasta County; breeds along length of west slope (Grinnell and Miller 1944).

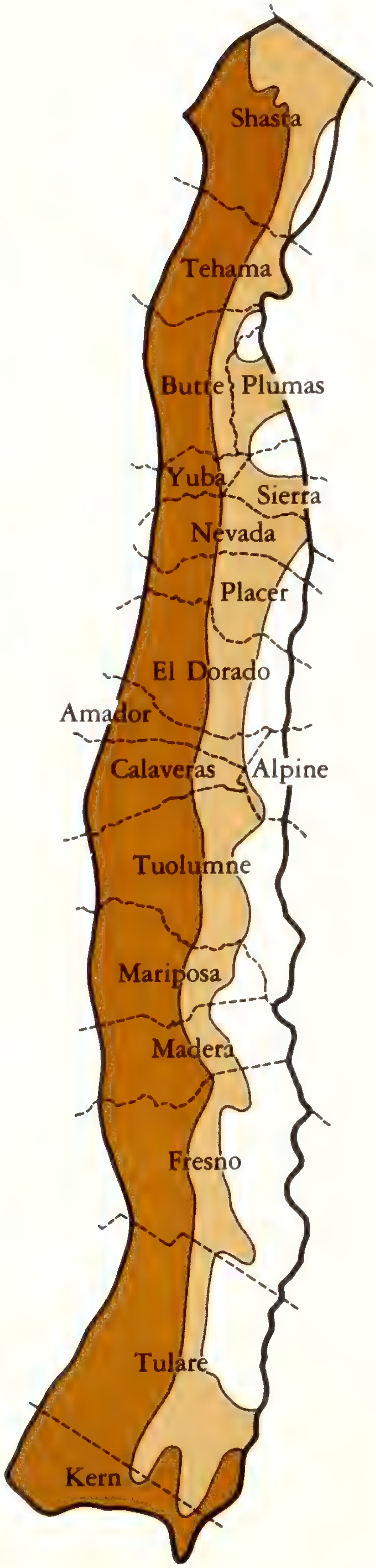
TERRITORY/HOME RANGE: In Iowa, for 44 breeding territories, the "arc" around nests averaged 150 ft (46 m). Home range was twice this size (Glover 1953a).

FOOD HABITS: Dives for insects, crustaceans, and small fish.

OTHER: Susceptible to biological concentration of hard pesticides on watersheds draining into its aquatic habitats.

REFERENCES: Grinnell and Miller 1944, Glover 1953a, Palmer 1962, Chabreck 1963.





Great Blue Heron

B004 *(Ardea herodias)*

STATUS: No official listed status. Uncommon resident.

DISTRIBUTION/HABITAT: Found in all successional stages from annual grasslands through lodgepole pine. Regualrly moves upslope after breeding, rarely up to treeline. Some nonbreeding individuals present year-round up to 4000 ft (1220 m).

SPECIAL HABITAT REQUIREMENTS: Ponds, lakes, streams, rivers, marshes, or wet meadows.

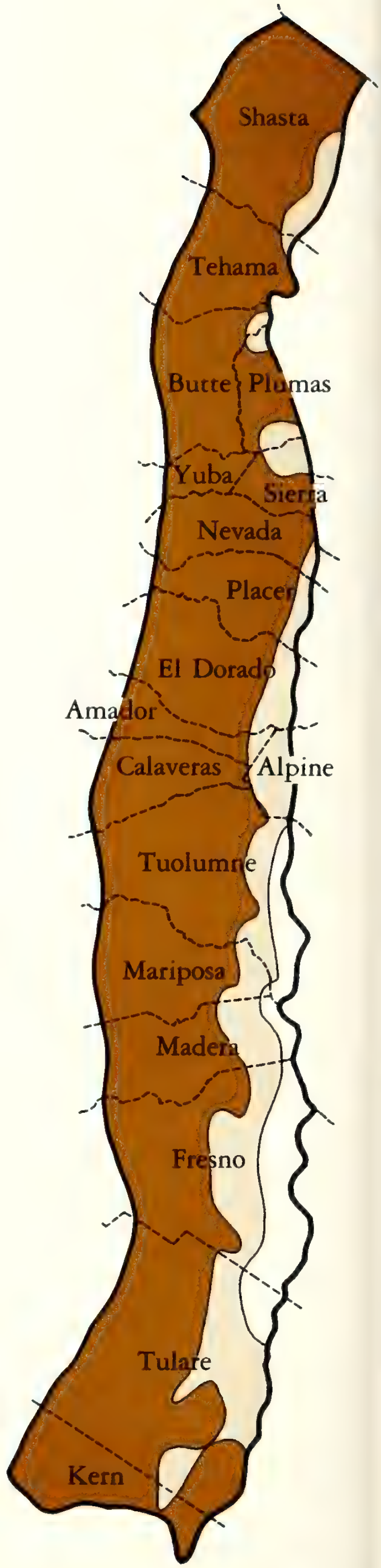
BREEDING: Breeds from mid-February to early September, with peak from early April to early July. Nests in live or dead trees, on cliffsides, or sequestered spots in marshes. Will nest on ground; prefers tops of tall trees often above 50 ft (15.2 m). Only one active rookery known on west slope, in a riparian deciduous woodland along Kern River, Kern County, at 3000 ft (915 m) elevation. Clutch size from 1 to 8 eggs, with 3 or 4 most common.

TERRITORY/HOME RANGE: Breeding territory limited to nest and immediate surroundings. Feeding territories may be defended in nonbreeding season (Palmer 1962), particularly in linear habitats—along ditches, streams, and fence rows (Krebs 1974). May travel as far as 10 mi (16 km) from nest sites to foraging areas (Krebs 1974).

FOOD HABITS: Feeds on fish, crustaceans, insects, aquatic plants, and rodents. Forages in shallow water, along banks of a body of water, and in open fields. Stands and waits or walks slowly, standing upright.

OTHER: Susceptible to biological concentration of hard pesticides on watersheds draining into its aquatic habitats.

REFERENCES: Palmer 1962, Pratt 1970, Wilburn 1971, Jackman and Scott 1975.



Green Heron

B005 *(Butorides striatus)*

STATUS: No official listed status. A rare summer visitor and migrant; may breed in scattered locations.

DISTRIBUTION/HABITAT: Found mainly in riparian deciduous zones, more common in the foothills below 1000 ft (305 m), but may be found regularly above that elevation.

SPECIAL HABITAT REQUIREMENTS: Ponds, lakes, or slow-moving streams or rivers with tree border.

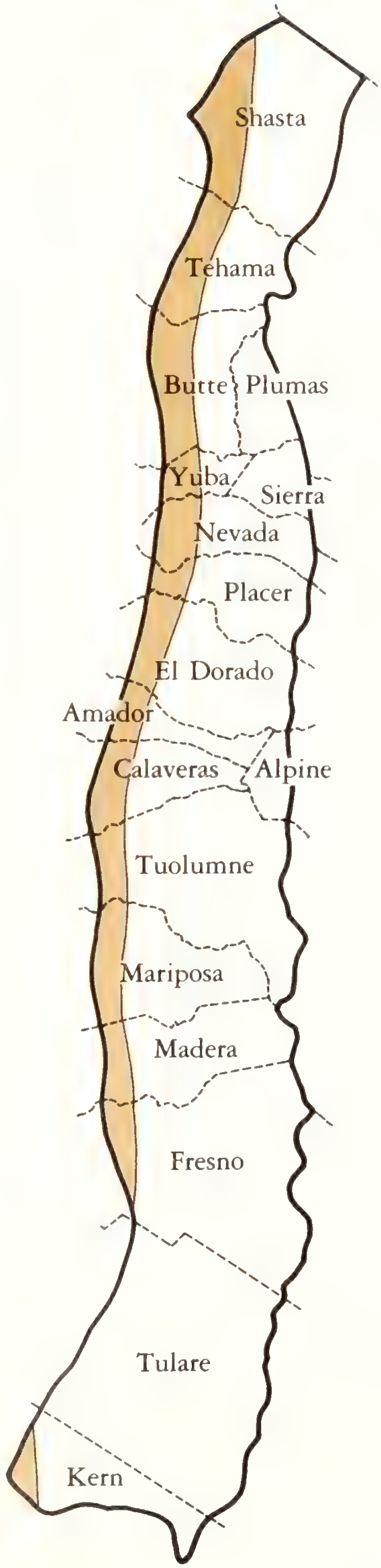
BREEDING: Breeds from late March to mid-August, with peak from early June to late July. Nests in trees, often willows, usually near water and often in dense tangles in crowns of middle-aged trees from near ground to more than 30 ft (9 m). Clutch size from 3 to 6, with 3 or 4 most usual.

TERRITORY/HOME RANGE: No data available on home range. Breeding territory on Long Island, New York, averaged 60 ft (18.3 m) in radius. Territory shrinks from 60 ft (18.3 m) to 3 ft (0.9 m) radius after pair formation. Some also defend a feeding territory of unknown size (Meyerriecks 1960).

FOOD HABITS: Eats primarily small fish, crustaceans, and insects, obtained by standing and waiting, or walking slowly, typically in crouched position. Feeds in shallow water.

OTHER: Susceptible to biological concentration of hard pesticides on watersheds draining into its aquatic habitats.

REFERENCES: Meyerriecks 1960, Palmer 1962.



Black-crowned Night Heron

B006 *(Nycticorax nycticorax)*

STATUS: No official listed status. On the 1978 Audubon Society Blue List. Rare summer visitor and migrant; may winter below 40° latitude.

DISTRIBUTION/HABITAT: Found in annual grasslands through chaparral and riparian deciduous types. Primarily found under various canopy closures of pole, medium, and large tree stages. More common in foothills below 1000 ft (305 m); a few recorded above this elevation, and may be found there regularly; breed in a few localities.

SPECIAL HABITAT REQUIREMENTS: Ponds, lakes, marshes, slow streams with pools, or rivers.

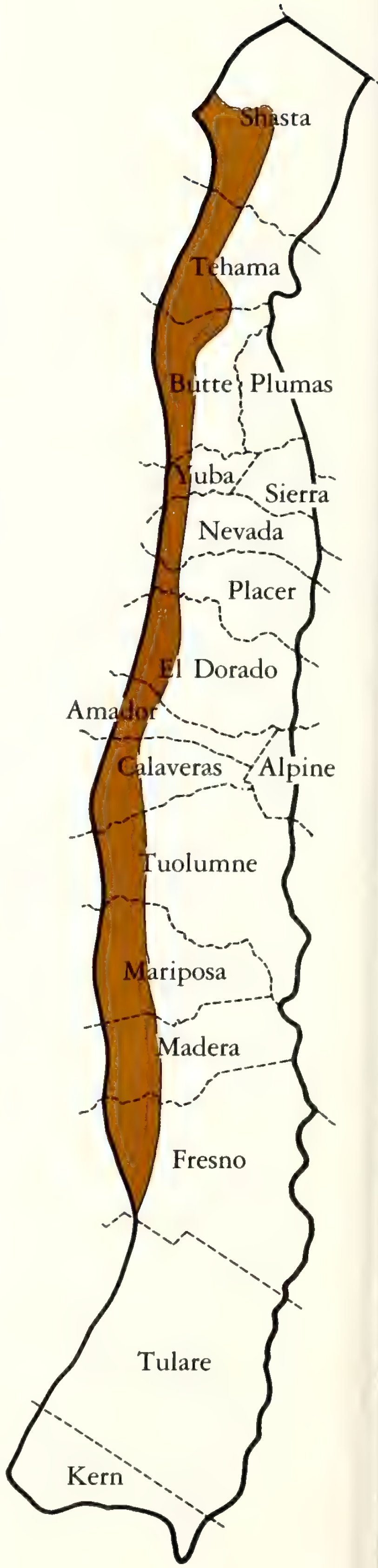
BREEDING: Breeds from early April to mid-September, with peak from early June to early August. Nests in small to very large colonies in trees or sometimes in tules or cattails 0 to 160 ft (0 to 49 m) above the ground. Clutch size from 1 to 6, with 3 to 5 most usual.

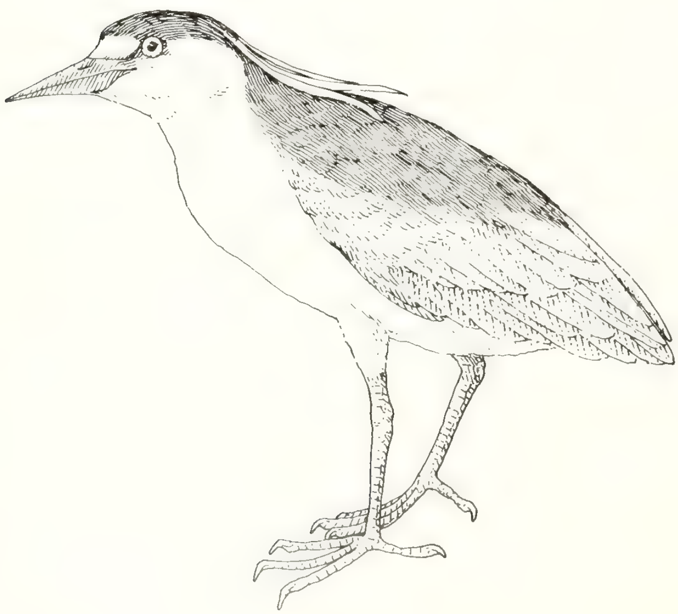
TERRITORY/HOME RANGE: No data available on home range. On Long Island, New York, breeding territory was less than 3 ft (1 m) around the nest (Allen and Mangels 1940). Some have winter roost territory, or feeding territory, or both, but size unknown.

FOOD HABITS: Feeds at night, mainly on small fish, crustaceans, aquatic insects, and frogs. Forages in shallow water by standing and waiting or walking slowly.

OTHER: Susceptible to biological concentration of hard pesticides on watersheds draining into its aquatic habitats.

REFERENCES: Allen and Mangels 1940, Palmer 1962, Ives 1972.





Whistling Swan

B007 *(Olor columbianus)*

STATUS: No official listed status. Rare winter visitor to large, freshwater lakes at low elevations.

DISTRIBUTION/HABITAT: Reported in winter on suitable lakes from annual grassland region to as high as ponderosa pine and black oak regions in northern portion of the Sierra Nevada. Apparently habitat adjacent to water is unimportant; have been recorded in both open and forested sites.

SPECIAL HABITAT REQUIREMENTS: Shallow and productive lakes.

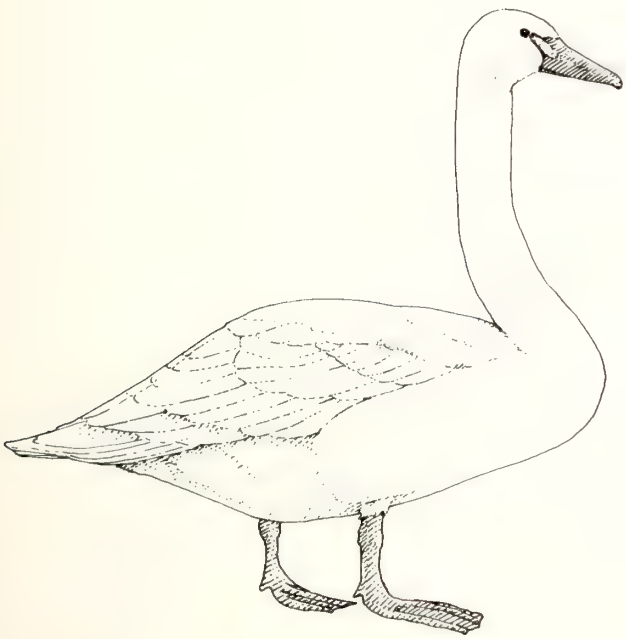
BREEDING: Does not breed on west slope of the Sierra Nevada.

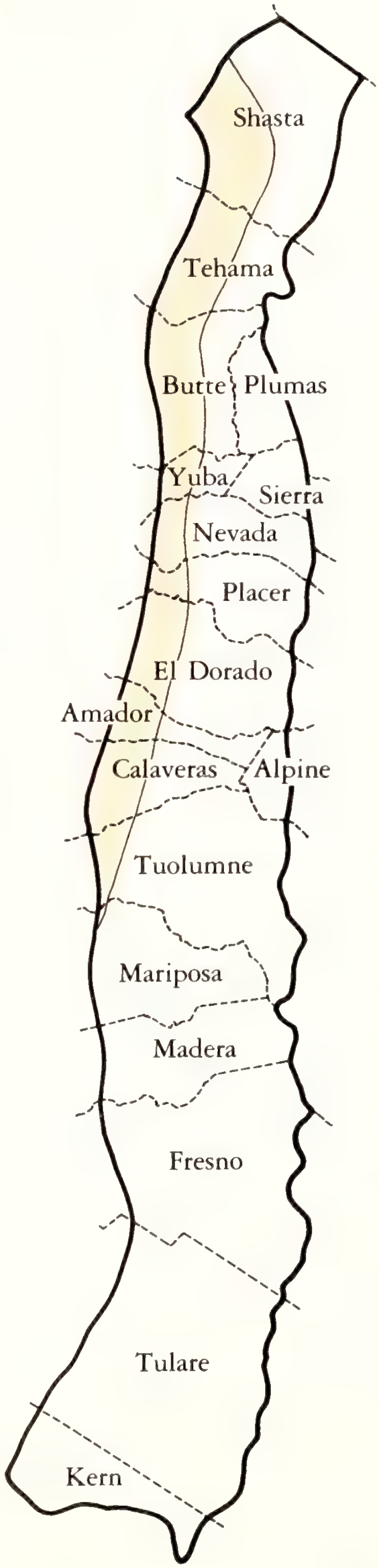
TERRITORY/HOME RANGE: Not territorial in winter. Flies 10 to 15 mi (16 to 24 km) from aquatic roosts in Maryland to feed in fields (Bellrose 1976). A radio-tagged bird in Maryland regularly flew 7 to 8 mi (11 to 13 km) between two areas over an 18-day period (Sladen and Cochran 1969).

FOOD HABITS: Aquatic vegetation, grasses, and cultivated crops make up the diet. Gathers food from bottoms of shallow, eutrophic lakes and agricultural fields. Uproots aquatic vegetation, grazes, and tips up, with head underwater.

OTHER:

REFERENCES: Grinnell *et al.* 1918, Johnsgard 1975b, Bellrose 1976, Palmer 1976.





Canada Goose

B008 *(Branta canadensis)*

STATUS: No official listed status. Game species. Uncommon spring and fall migrant and winter visitor; rare and localized nester in the northern Sierra Nevada.

DISTRIBUTION/HABITAT: Known to breed at lakes as high as 6000 ft (1830 m) in Lassen region (starred on range map). Migrating flocks traveling between nesting areas in Great Basin and wintering grounds in Central Valley recorded. Flocks infrequently stop briefly to feed and rest in large meadows or lakes throughout the Sierra Nevada.

SPECIAL HABITAT REQUIREMENTS: Lakes.

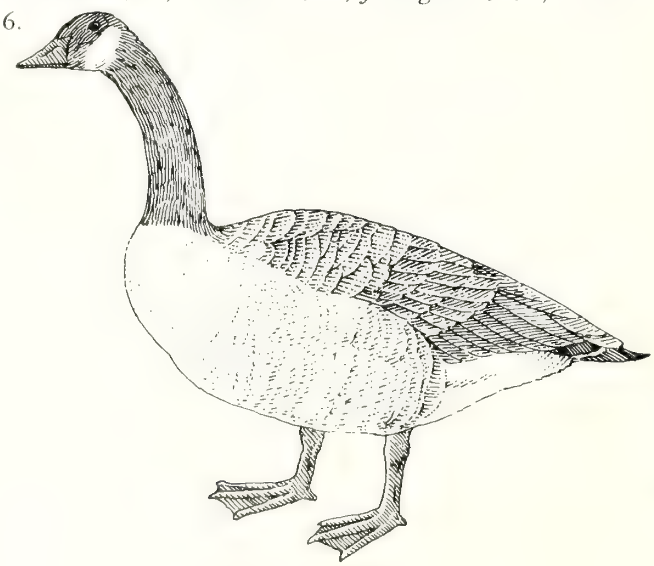
BREEDING: Breeds from mid-March to late July, with peak from mid-May to mid-July. Typically nests on islands on the ground or uses a dry nest foundation, such as stump, platform, or tree. Nest height varies, depending on type of foundation structure available Clutch size from 4 to 10, with 5 to 7 most frequent.

TERRITORY/HOME RANGE: Breeding territories include nest site and suitable loafing area; size varies with characteristics of vegetation and aggressiveness of gander. In Alberta, a map of territories suggests a size range from about 800 ft^2 to at least 2.3 acres (70 m^2 to 0.9 ha) with nest densities of 8.0, 10.7, and 9.2 nests/acre (19.8, 26.4, and 22.7 nests/ha) for a 3-year period (Ewaschuk and Boag 1972). A high nesting density of about 62/acre (153/ha) on an island at Honey Lake Refuge, Lassen County, reported (Naylor 1953). Breeding home range depends on distance from nest to suitable feeding areas. In Utah (Williams and Sooter 1940) and North Dakota (Hammond and Mann 1956), foraged up to 5 mi (8 km) from nest. Broods in Montana moved 2 to 10 mi (3.2 to 16 km) from nest to feeding areas and remained until they could fly (Geis 1956). In winter, foraged at least 30 mi (48 km) from roosting lakes in Texas (Glazener 1946).

FOOD HABITS: Cereal crops, clovers, grasses, aquatic vegetation, snails, tadpoles, and insects are major foods. Obtains food from water by probing in mud, and tipping up, with head underwater, and on ground, by grazing.

OTHER:

REFERENCES: Grinnell *et al.* 1918, Dimmick 1968, Johnsgard 1975b, Bellrose 1976, Palmer 1976.



Snow Goose

B009 *(Chen caerulescens)*

STATUS: No official listed status. Game species. Extremely rare fall migrant and winter visitor.

DISTRIBUTION/HABITAT: Most records are of flocks in flight; have been documented as landing on lakes away from timbered areas, from annual grasslands up to chaparral zone.

SPECIAL HABITAT REQUIREMENTS: Lakes.

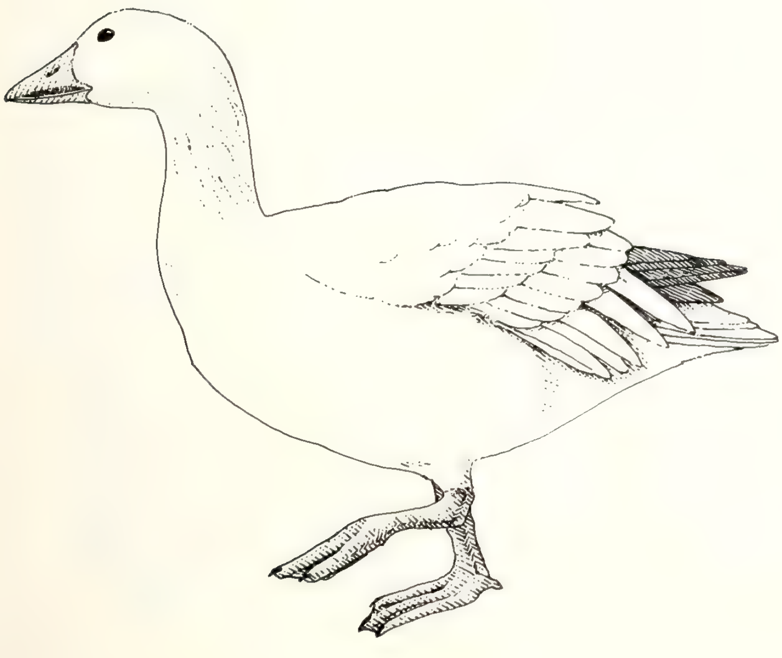
BREEDING: Does not breed on west slope of the Sierra Nevada.

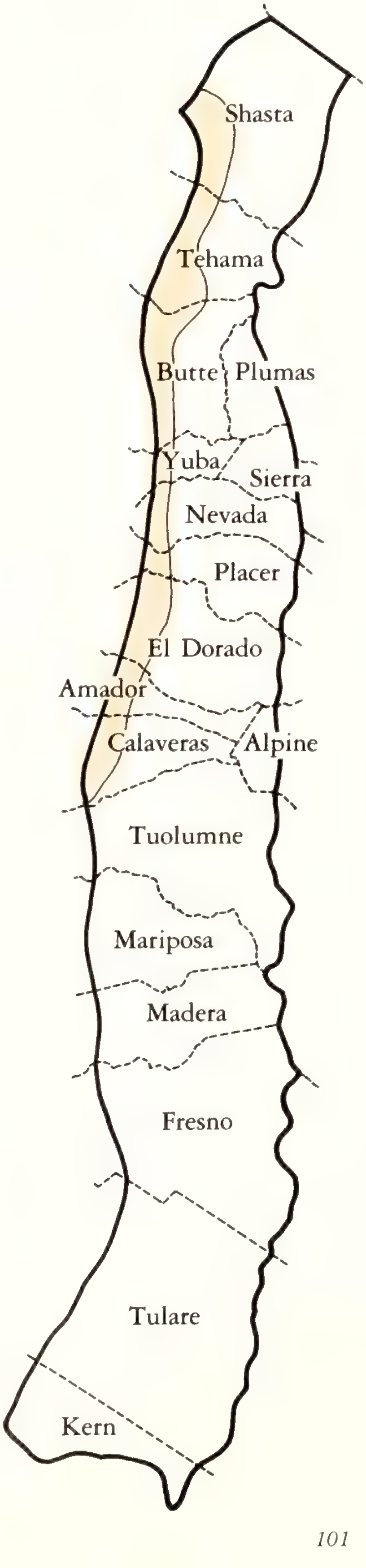
TERRITORY/HOME RANGE: Little information on winter home range. In Texas, flew up to 30 mi (48 km) to feeding areas (Glazener 1946). Not territorial in winter.

FOOD HABITS: Feeds on bulrushes, marsh grasses, pasture grasses, and cultivated grains. Food gathered from muddy bottoms of shallow ponds and cultivated fields. Uproots aquatic vegetation and grazes in pastureland.

OTHER: One of the most social of all species of waterfowl.

REFERENCES: Grinnell *et al.* 1918, Johnsgard 1975b, Bellrose 1976, Palmer 1976.





Mallard

B010 *(Anas platyrhynchos)*

STATUS: No official listed status. Game species. Uncommon breeder; fairly common winter visitor at low elevations.

DISTRIBUTION/HABITAT: Recorded breeding in Yosemite National Park, west side of the Sierra Nevada, to elevations of 9600 ft (2930 m) (Beedy, unpubl.). Numerous lower elevation nesting records, usually associated with lakes and smooth-flowing rivers, irrespective of surrounding vegetation. Most winter records below 4000 ft (1220 m).

SPECIAL HABITAT REQUIREMENTS: Ponds, lakes, slow-moving streams or rivers.

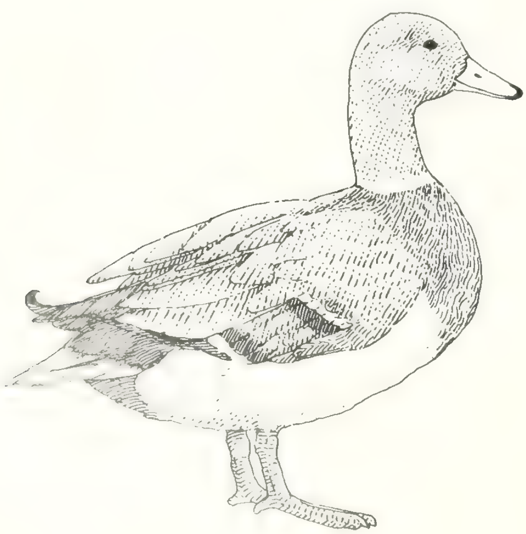
BREEDING: Breeds from mid-March to mid-July, with peak from late April to late June. Nests on the ground, usually in tall, herbaceous vegetation, usually within 328 ft (100 m) of water. Has been noted nesting in dense woods. Clutch size from 1 to 18 (mostly 6 to 12), with mean of 9.

TERRITORY/HOME RANGE: In prairie potholes country of Manitoba, nesting home range size averaged 700 acres (283 ha) (Dzubin 1955). Average breeding home ranges of radio-tagged birds in timbered areas of Minnesota were 519 acres (210 ha) (12 females) and 593 acres (240 ha) (12 males); the range was 163 acres (66 ha) (a female) to 1878 acres (760 ha) (a pair) (Gilmer *et al.* 1975). In winter, may fly up to 30 to 40 mi (48 to 64 km) to forage from roost sites. Does not defend rigid territories, but area immediately surrounding the female usually defended by the male. Nesting density in South Dakota prairie potholes reported as 6.7 pairs/mi^2 (2.6 pairs/km^2) (Drewien and Springer 1969).

FOOD HABITS: Feeds on cultivated grains, pondweeds, grasses, insects, crustaceans, and small fish. Food taken from shallow water ponds and from the ground. Dabbles on water surface, tips up in shallow water, and grazes in fields.

OTHER: Most abundant waterfowl species in the Sierra Nevada.

REFERENCES: Anderson *et al.* 1974, Pospahala *et al.* 1974, Johnsgard 1975b, Bellrose 1976, Palmer 1976.



Pintail

B011 *(Anas acuta)*

STATUS: No official listed status. Game species. Very rare spring and fall migrant and winter visitor; accidental in summer.

DISTRIBUTION/HABITAT: No confirmed nesting records in the Sierra Nevada, though pair seen at 8600 ft (2620 m) in Tuolomne meadows, June 4, 1977 (Beedy, unpubl.). Prefers areas of shallow water surrounded by open terrain; generally found only at lower elevations in the Sierra Nevada.

SPECIAL HABITAT REQUIREMENTS: Ponds, lakes.

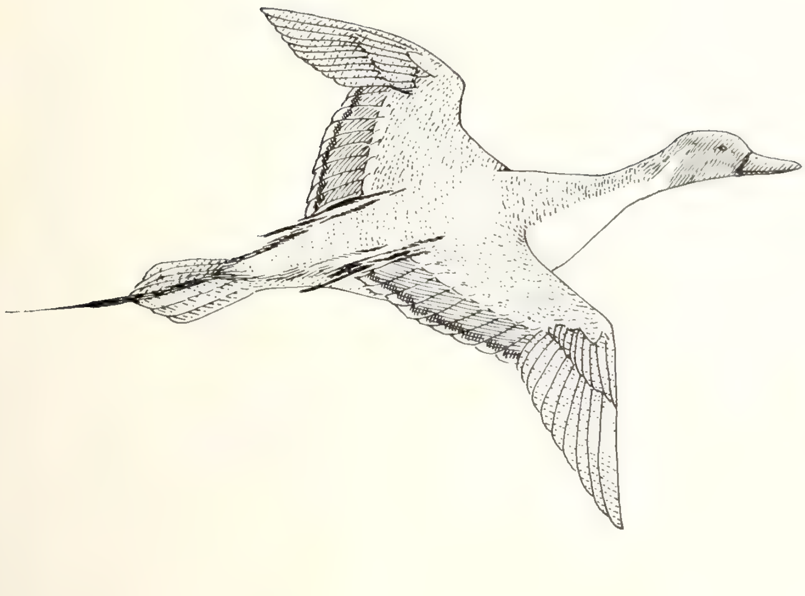
BREEDING: Not known to breed on west slope of the Sierra Nevada.

TERRITORY/HOME RANGE: No information on winter home range; not territorial in winter.

FOOD HABITS: Feeds on cultivated grain, seeds of bulrushes, pondweeds, aquatic and terrestrial insects. Food obtained from bottoms of shallow ponds and dry ground. Dabbles at water surface, tips up for bottom feeding, and grazes.

OTHER:

REFERENCES: Fuller 1953, Johnsgard 1975b, Bellrose 1976, Palmer 1976.



Green-winged Teal

B012 *(Anas crecca)*

STATUS: No official listed status. Game species. Rare fall and spring migrant and winter visitor.

DISTRIBUTION/HABITAT: Most records of birds in freshwater ponds and marshes at low elevations up to ponderosa pine and black oak woodland zones.

SPECIAL HABITAT REQUIREMENTS: Ponds, lakes, or marshes.

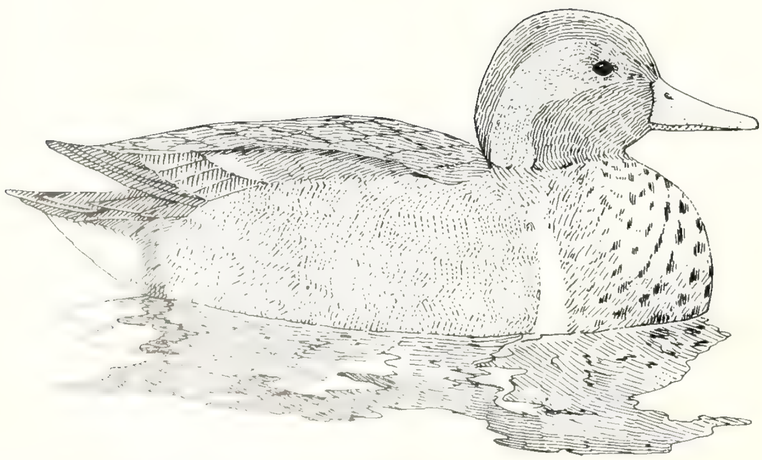
BREEDING: Does not breed on west slope of the Sierra Nevada.

TERRITORY/HOME RANGE: No data on winter home range; not territorial in migration or winter.

FOOD HABITS: Feeds on seeds of aquatic plants, grain, weed seed, and mast; also insects, crustaceans, snails, and tadpoles. Food taken from muddy shores of ponds, bottoms of shallow ponds and, occasionally, fields. Probes in the mud, tips up for bottom feeding, grazes in fields.

OTHER:

REFERENCES: Moisan *et al.* 1967, Johnsgard 1975b, Bellrose 1976, Palmer 1976.



Cinnamon Teal

B013 *(Anas cyanoptera)*

STATUS: No official listed status. Game species. Rare spring and summer visitor.

DISTRIBUTION/HABITAT: Found in low-elevation ponds and marshes from annual grasslands up to ponderosa pine and black oak woodland zones.

SPECIAL HABITAT REQUIREMENTS: Ponds, lakes, slow-moving streams, or rivers.

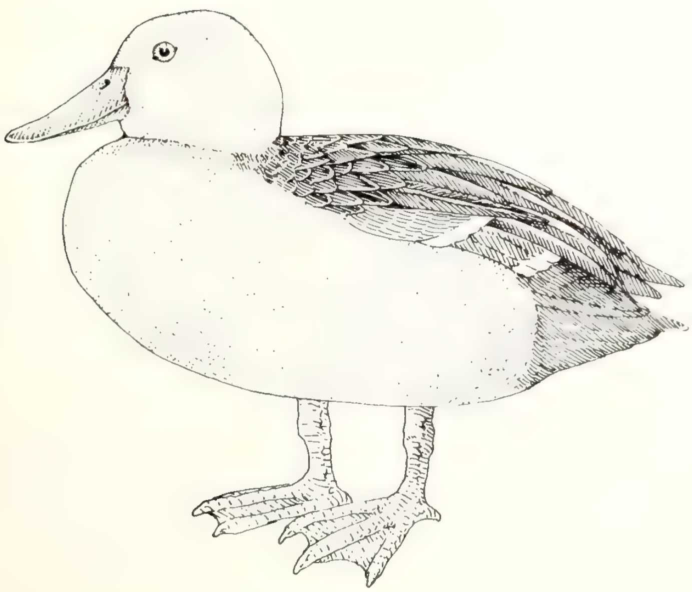
BREEDING: Not known to breed on west slope of the Sierra Nevada; observed nesting in adjacent areas to west and northeast.

TERRITORY/HOME RANGE: No data on home range; territorial only when nesting.

FOOD HABITS: Feeds on seeds and vegetative portions of pondweeds, bulrushes, and sedges; also takes mollusks and insects. Food taken from pond edges, bottoms of shallow ponds, and dry fields. Probes in mud, tips up for bottom feeding, grazes in fields.

OTHER:

REFERENCES: Spencer 1953, Johnsgard 1975b, Bellrose 1976, Palmer 1976.



American Wigeon

B014 *(Anas americana)*

STATUS: No official listed status. Game species. Extremely rare fall and spring migrant and winter visitor.

DISTRIBUTION/HABITAT: More than other members of genus, prefers deeper lakes or wide, slow-moving sections of rivers. Recorded generally at low elevations, up to ponderosa pine and black oak zone, typically in ponds and lakes surrounded by grass/forb or shrub-covered land.

SPECIAL HABITAT REQUIREMENTS: Ponds, lakes, or slow-moving streams or rivers.

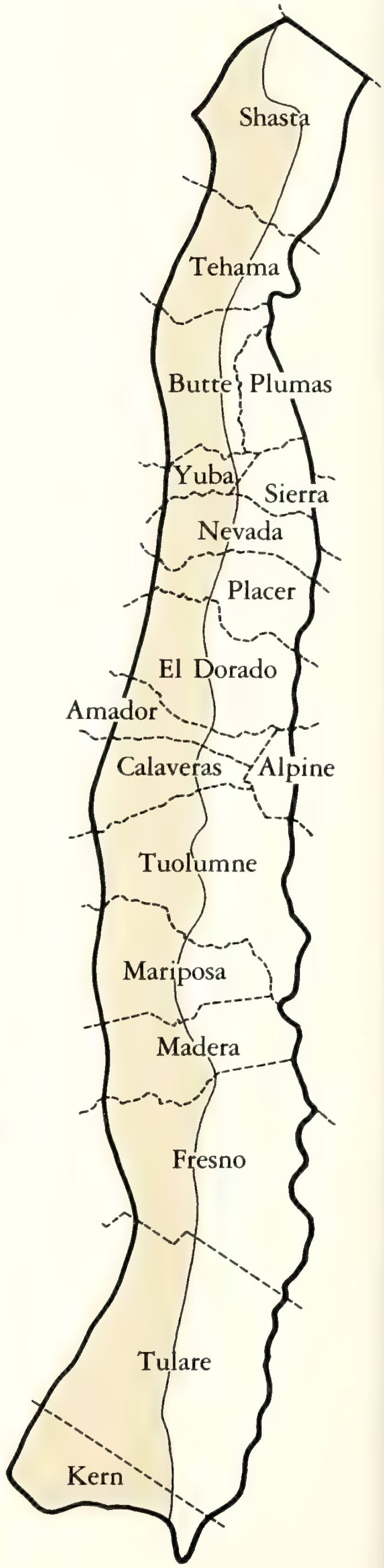
BREEDING: Does not breed in the western Sierra Nevada.

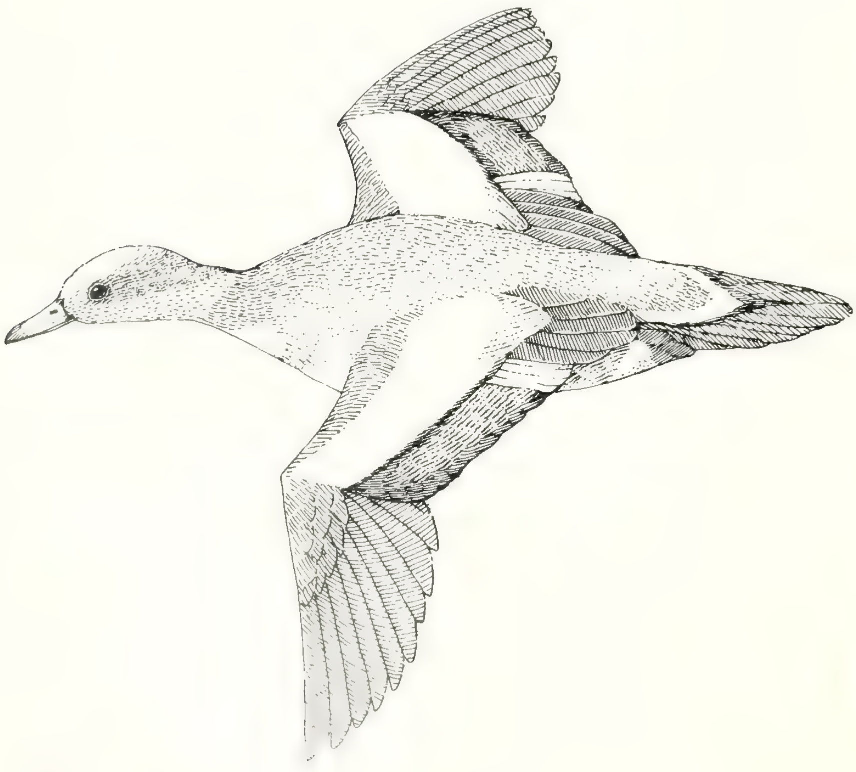
TERRITORY/HOME RANGE: No data on home range; not territorial in winter.

FOOD HABITS: Eats wigeon grass, pondweed, aquatic and terrestrial insects. Feeds in pastureland and fields, often wet, and from the edges and bottoms of ponds. Grazes in fields, probes around pond edges, tips up for bottom feeding, and dives. Recorded stealing aquatic vegetation from diving ducks, such as canvasbacks and redheads (Grinnell *et al.* 1918).

OTHER:

REFERENCES: Grinnell *et al.* 1918, Johnsgard 1975b, Bellrose 1976, Palmer 1976.





Northern Shoveler

B015 *(Anas clypeata)*

STATUS: No official listed status. Game species. Extremely rare spring and fall migrant, and winter visitor. Only one nesting record (starred on range map).

DISTRIBUTION/HABITAT: Generally distributed at low elevations, up to ponderosa pine and black oak woodland zone, where found in shallow ponds adjacent to open country. One nesting record reported at Ostrander Lake, at 8600 ft (2620 m), in Yosemite National Park (Gaines 1977).

SPECIAL HABITAT REQUIREMENTS: Ponds, lakes, or slow-moving streams or rivers.

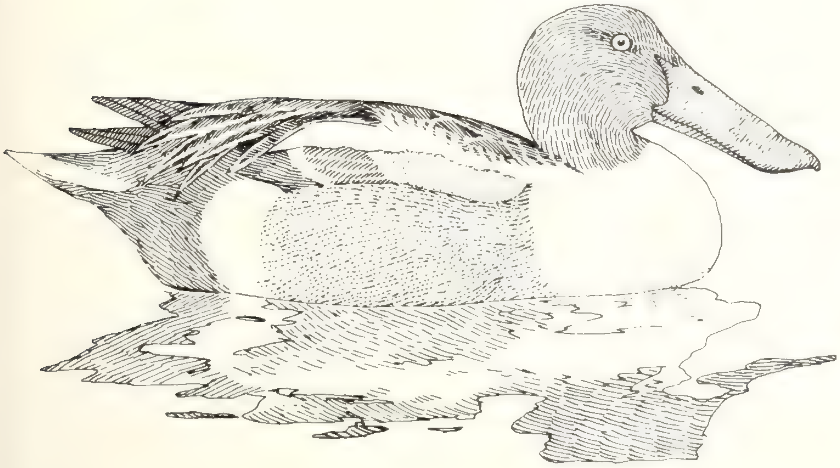
BREEDING: Breeds from mid-May to early August, with peak from mid-June to mid-July. Nest typically placed among short grass within 50 yds (46 m) of water. Clutch size from 5 to 14, with mean of 10 or 11.

TERRITORY/HOME RANGE: Some observers indicate does not defend territories; males defend only small areas around mates (Hori 1963). A defended core area (territory) noted within each pair's breeding home range (Poston 1969, 1974). Territories before egg laying averaged 7.2 acres (2.9 ha) (n= 10), with range from 3.2 to 12.4 acres (1.3 to 5.0 ha) (Seymour 1974). During egg laying and incubation, core area decreased to a mean of 2.2 acres (0.9 ha) and a range of 0.25 to 3.7 acres (0.1 to 1.5 ha). Breeding home ranges from 15 to 90 acres (6 to 36 ha), with a mean of 49.7 acres (18.7 ha) reported in the Midwest (Poston 1969). Breeding home ranges from 20 to 128 acres (8.1 to 52 ha), with an average of 76 acres (31 ha) reported in Alberta (Poston 1974).

FOOD HABITS: Feeds on freshwater clams, aquatic insects, copepods, pondweeds, and bulrushes. Food taken from shallow water and muddy bottoms of ponds. Feeds on water surface, and dabbles in muddy shallows.

OTHER:

REFERENCES: Poston 1969, 1974; Johnsgard 1975b; Bellrose 1976; Palmer 1976.



Wood Duck

B016 *(Aix sponsa)*

STATUS: No official listed status. Game species. Uncommon to fairly common resident in suitable habitat.

DISTRIBUTION/HABITAT: Breeds along streams or ponds near oaks, for food and suitable nest cavities, from blue oak savannahs up to ponderosa pine and black oak woodland zones. More abundant in northern California, particularly along the Cosumnes, Mokelumne, Tuolumne, Merced, San Joaquin, and Kings Rivers. High abundances also reported in Shasta and Plumas Counties (Naylor 1960).

SPECIAL HABITAT REQUIREMENTS: Ponds, slow-moving streams; nest cavities; oaks.

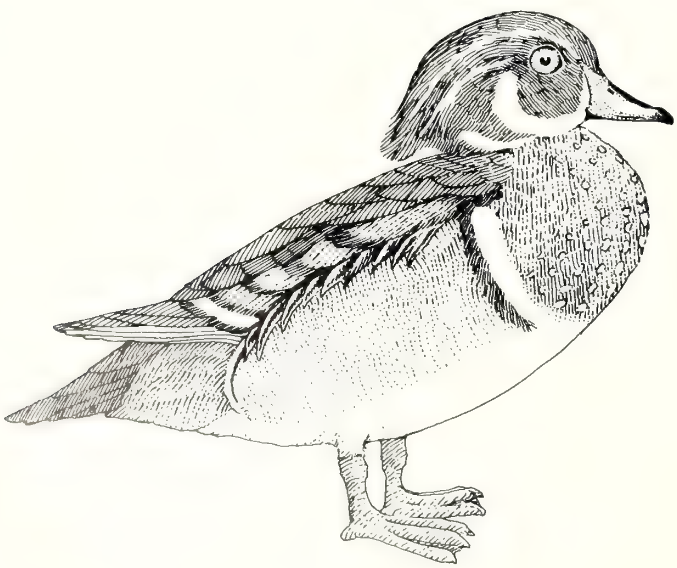
BREEDING: Breeds from mid-April to mid-July, with peak from mid-May to mid-June. Nests in cavity. Optimum natural cavities 20 to 50 ft (6 to 15 m) up, with entrance of 4 in (10 cm) in diameter (McGilvery 1968), situated in stands of willows, cottonwoods, or oaks. Clutch size from 3 to 15, with mean of 12.2.

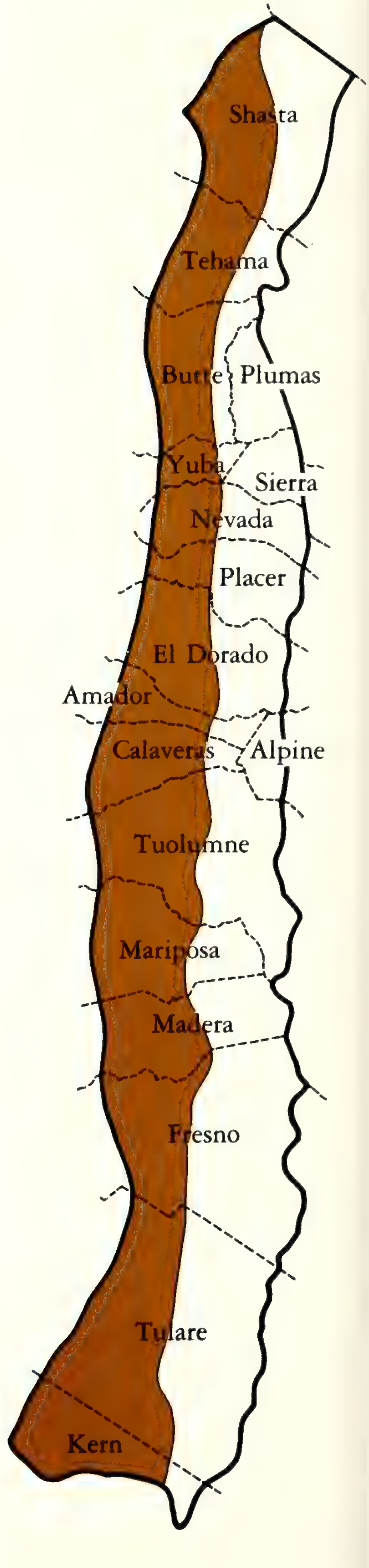
TERRITORY/HOME RANGE: Does not defend nest; males defend small space around mate (Grice and Rogers 1965). Home range of breeding males averaged 500 acres (200 ha) and of unpaired males 1300 acres (526 ha) in Minnesota (Gilmer 1971). Flightless broods ranged from 0 to 3.5 mi (0 to 5.6 km) along an Ohio river; a brood of fledged young ranged from 0 to 8 mi (0 to 12.8 km) (Stewart 1958).

FOOD HABITS: Eats primarily acorns, insects, aquatic plants, and cultivated grains. Takes acorns from forest floor; in water tips up to feed underwater; sometimes females dive.

OTHER: Numbers markedly reduced in past as result of reduction in suitable wooded riparian habitat by logging. Placement of artificial nest boxes in habitats where natural cavities are limiting resulted in substantial increase in numbers. Such boxes should be "predator proof" (Bellrose 1976), within 400 yds (375 m) of stream (Ball *et al.* 1975), and spaced widely (Jones and Leopold 1967).

REFERENCES: Naylor 1960, Trefethen 1966, Bellrose 1976, Palmer 1976.





Redhead

B017 *(Aythya americana)*

STATUS: No official listed status. Game species. Extremely rare winter visitor.

DISTRIBUTION/HABITAT: Found in fall and winter on deep lakes at low elevations, from annual grassland zone up through the digger pine-oak type; prefers ponds in nontimbered areas.

SPECIAL HABITAT REQUIREMENTS: Lakes with deep water.

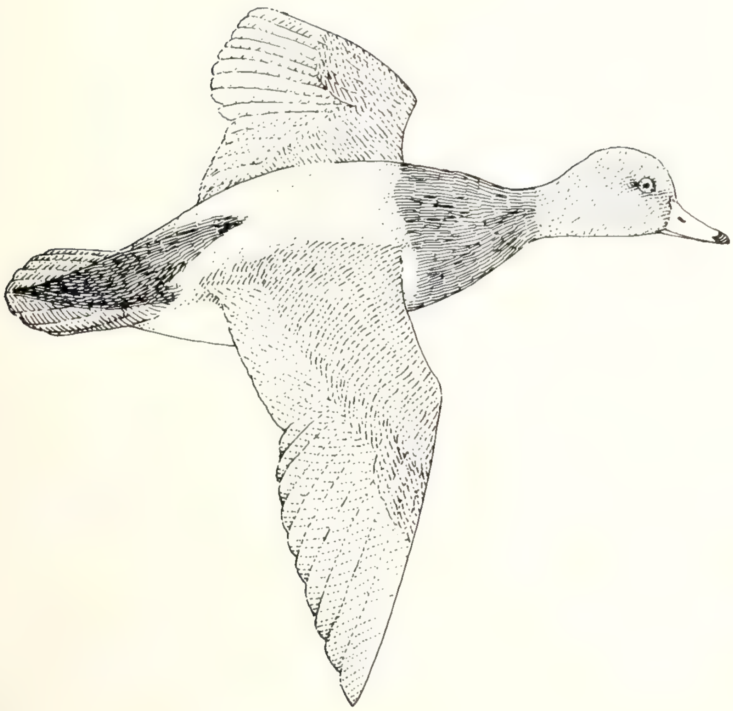
BREEDING: Does not breed in the western Sierra Nevada.

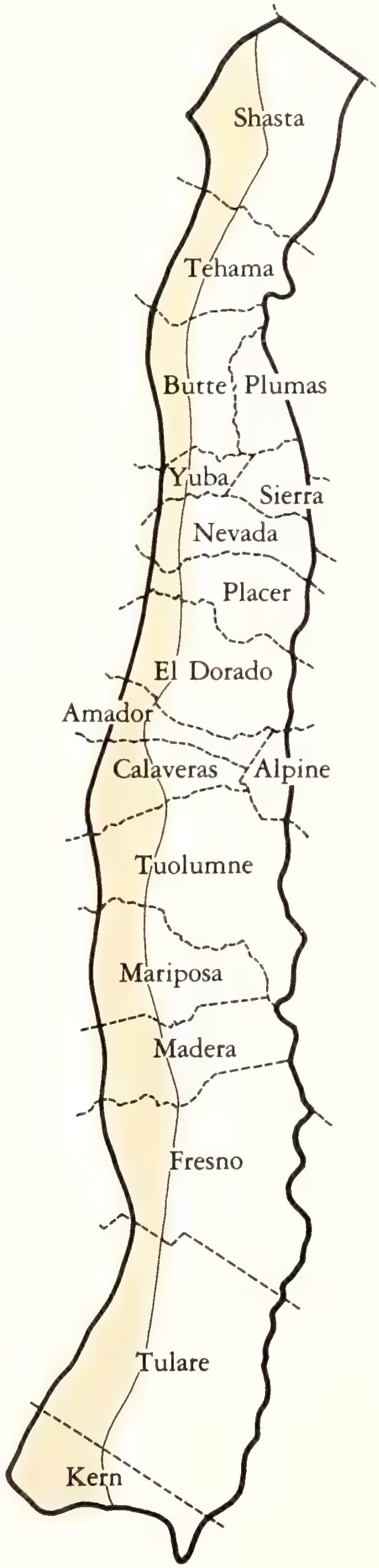
TERRITORY/HOME RANGE: No data available on winter home range; not territorial in the western Sierra Nevada.

FOOD HABITS: Eats seeds and vegetative parts of pondweeds and bulrushes; also algae, insects, fish, frogs, and mollusks. Dives, often to considerable depths, to obtain food.

OTHER:

REFERENCES: Grinnell *et al.* 1918, Johnsgard 1975b, Bellrose 1976, Palmer 1976.





Ring-necked Duck

B018 *(Aythya collaris)*

STATUS: No official listed status. Game species. Rare spring and fall migrant and winter visitor; a few nesting records at Buck's Lake (starred on range map) in the northern Sierra Nevada (T. Manolis, pers. commun.).

DISTRIBUTION/HABITAT: Breeds infrequently around ponds with marsh vegetation in mixed-conifer and Jeffrey pine types. In fall and winter, found on shallow ponds of varying size and surrounding vegetation types, from annual grassland areas up to ponderosa pine and black oak woodland types.

SPECIAL HABITAT REQUIREMENTS: Ponds, lakes.

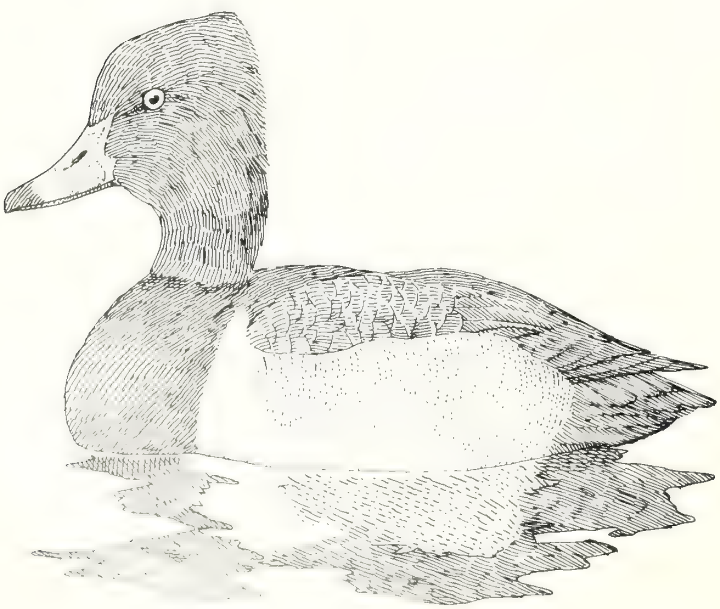
BREEDING: Breeds from early May to early August, with peak from mid-June to mid-July. Nests on reasonably dry spots with suitable cover, usually sedge, on hummocks or clumps of open marsh. Range from 0 to 400 ft (0 to 122 m) from open water, averaging 81 ft (25 m). Clutch size from 5 to 14, with mean of 7.9.

TERRITORY/HOME RANGE: No data on home range. Male defends small space around mate (Mendall 1958). Nesting density in Maine varied from one pair per 1.6 acres (0.6 ha) to one pair per 23 acres (9 ha) (Mendall 1958).

FOOD HABITS: Eats primarily pondweeds, bulrushes, sedges, snails, clams, and aquatic insect larvae. Dives for food, usually to depths of 6 ft (1.8 m) or less. Captures food in water or takes it from the muddy bottom.

OTHER: Nesting reports infrequent enough that could be considered nonbreeder in the western Sierra Nevada. Nearly all sightings between November 21 and March 23.

REFERENCES: Mendall 1958, Johnsgard 1975b, Bellrose 1976, Palmer 1976.



Canvasback

B019 *(Aythya valisineria)*

STATUS: No official listed status; on the 1978 Audubon Society Blue List. Game species. Rare winter visitor; less common in southern than northern Sierra Nevada.

DISTRIBUTION/HABITAT: A fairly common species in winter in many inland areas of California, but rarely seen in the Sierra Nevada. Frequents large, open lakes with large quantities of submerged aquatic vegetation, in annual grassland, blue oak, and digger pine-oak zones. Usually avoids lakes in timbered sections.

SPECIAL HABITAT REQUIREMENTS: Lakes.

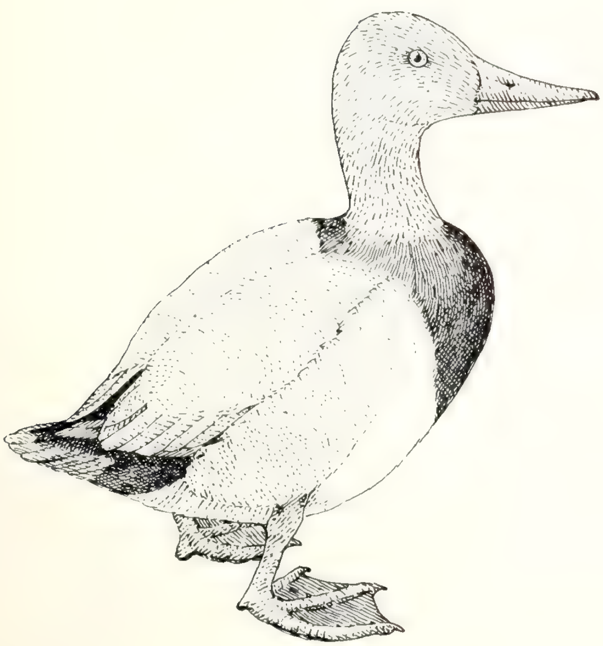
BREEDING: Does not breed in the western Sierra Nevada.

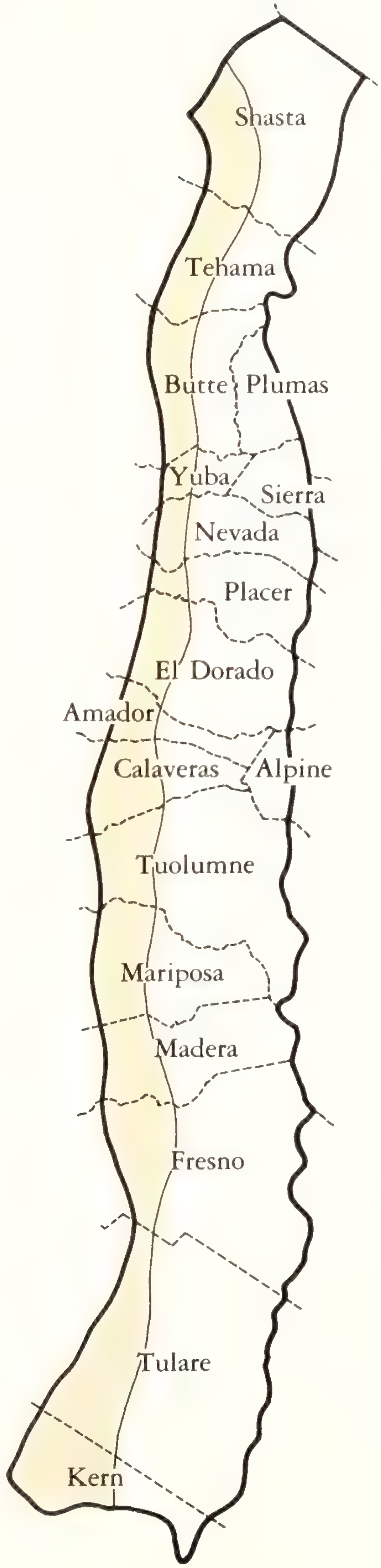
TERRITORY/HOME RANGE: No data on winter home range; not territorial in winter.

FOOD HABITS: Major food items are pondweeds, bulrushes, wigeon grass, mollusks, insects, and fishes. Dives, often to great depths; some food taken from muddy bottom; feeds on water surface as well.

OTHER:

REFERENCES: Erickson 1948, Johnsgard 1975b, Bellrose 1976, Palmer 1976.





Lesser Scaup

B020 *(Aythya affinis)*

STATUS: No official listed status. Game species. Rare but regular fall migrant and winter visitor.

DISTRIBUTION/HABITAT: Generally found only on large lakes with much submerged aquatic vegetation, in annual grasslands and in grass/forb and shrub stages of blue oak savannahs and digger pine-oak woodlands. Observed in Yosemite Valley at 4000 ft (1220 m) (Gaines 1977); most sightings below 2000 ft (610 m).

SPECIAL HABITAT REQUIREMENTS: Ponds, lakes.

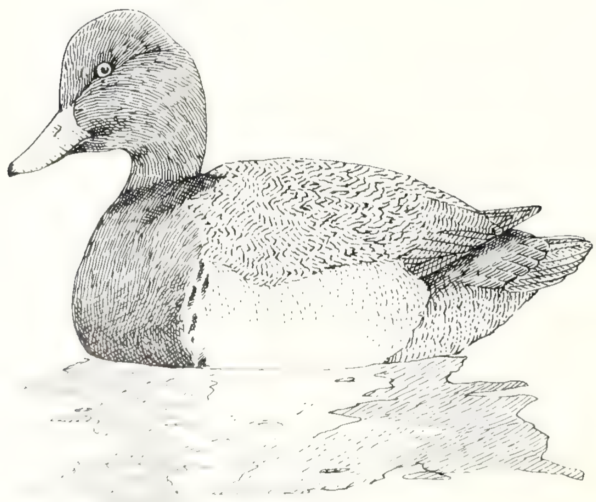
BREEDING: Does not breed in the western Sierra Nevada.

TERRITORY/HOME RANGE: Extensive use of large bodies of water, with ill-defined home range (Bellrose 1976); not territorial in winter.

FOOD HABITS: Eats mollusks, insects, fishes, wild celery, pondweeds, and wigeon grass. Dives, often to depths of greater than 25 ft (7.6 m), to obtain food in the water and on the bottom. Does some surface feeding.

OTHER:

REFERENCES: Gehrman 1951, Trauger 1971, Johnsgard 1975b, Bellrose 1976, Palmer 1976.



Barrow's Goldeneye

B021 *(Bucephala islandica)*

STATUS: No official listed status. Game species. Rare spring migrant and breeder (at least formerly—see Small 1974).

DISTRIBUTION/HABITAT: Breeds rarely around lakes and along streams from mixed-conifer forests upslope to lodgepole pine type, from Yosemite National Park northward. Reported nesting at a high elevation: 9200 ft (2800 m). Surrounding habitat must have some timber.

SPECIAL HABITAT REQUIREMENTS: Ponds, lakes; nest cavities.

BREEDING: Breeds from mid-April to mid-August, with peak from mid-June to mid-July. Nests in tree cavity; prefers flicker or pileated woodpecker holes. Most often uses pines, aspens, or cottonwoods in the Sierra Nevada. Nests usually within 100 yds (91 m) of water. In absence of nest cavities, uses nest boxes and also rocky crevices along smooth-flowing streams or high-elevation lakes. Clutch size from 4 to 15, with mean of 9.

TERRITORY/HOME RANGE: No data available. Two pairs reported on a 3-acre (1.2-ha) pond in the Cariboo District of British Columbia; territories consisted of 40 to 60 yds (37 to 55 m) of shoreline (Bellrose 1976).

FOOD HABITS: Eats primarily mollusks, isopods, amphipods, aquatic insects, grasses, and various water plants. Dives, usually less than 4 ft (1.2 m), turns over rocks, and probes in mud for food.

OTHER: Has never been common in the Sierra Nevada; main portion of nesting range is northward—in Oregon, Washington, British Columbia, Alaska, and the Rockies.

REFERENCES: Grinnell *et al.* 1918, Johnsgard 1975b, Bellrose 1976, Palmer 1976.

Bufflehead

B022 *(Bucephala albeola)*

STATUS: No official listed status. Game species. Rare but regular nester and spring migrant.

DISTRIBUTION/HABITAT: Breeds around small, timber-lined ponds or streams from blue oak savannah zone up to Jeffrey pine forests.

SPECIAL HABITAT REQUIREMENTS: Ponds, lakes, slow-moving streams; nest cavities.

BREEDING: Breeds from late April to early August, with peak from mid-June to mid-July. Nest placed in cavity in tree (commonly aspen), with preference for flicker holes, within 660 ft (200 m) of a lake or pond, and from 2 to 10 ft (0.6 to 3 m) above ground. Clutch size from 5 to 16, with mean of 8.6.

TERRITORY/HOME RANGE: In British Columbia, territories included a pond, or section of lake shoreline, and loafing sites; smallest pond suitable for isolated territory was about 2.5 acres (1 ha) (Erskine 1972). Two nests in some trees, but most nests about 330 yds (100 m) apart. Males seldom exhibited conflict unless females present, though pairs spaced out along the shore. Newly hatched broods moved from nest to feeding areas up to distances greater than 1 mi (1.6 km). Brood home ranges after young were 3 weeks old averaged 9.4 to 13.1 acres (3.8 to 5.3 ha), with range of 2.0 to 59 acres (0.8 to 24 ha).

FOOD HABITS: Eats larvae of aquatic insects, mollusks, crustaceans, and some aquatic vegetation. Obtains food from water and muddy bottom by diving; sometimes feeds on surface.

OTHER: Uncertain how common a nesting species in the Sierra Nevada during early 1900's. Presumably limited today by lack of suitable tree-lined ponds in undisturbed condition. Flickers and starlings significant competitors for nest cavities (Bellrose 1976).

REFERENCES: Erskine 1972, Johnsgard 1975b, Bellrose 1976, Palmer 1976.

Harlequin Duck

B023 *(Histrionicus histrionicus)*

STATUS: No official listed status. Game species. Historically a rare but regular nester along several rivers; now almost extinct in the Sierra Nevada.

DISTRIBUTION/HABITAT: Breeds along fast-flowing streams and rivers at high elevations, from 4000 to 9000 ft (1220 to 2740 m) in the central Sierra Nevada. Reported nesting along upper parts of the Merced, Cherry, Stanislaus, Tuolumne, and San Joaquin Rivers (Grinnell *et al.* 1918) but only three breeding records reported since 1927.

SPECIAL HABITAT REQUIREMENTS: Swift streams or rivers.

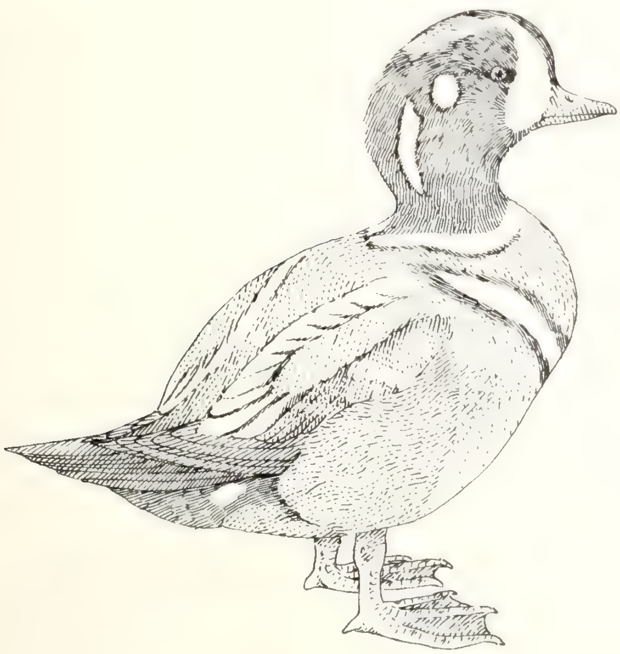
BREEDING: Breeds from mid-May to early August, with peak from mid-June to mid-July. Nests always next to turbulent, cold rivers, typically on the ground, under logs, driftwood, or rocks. Clutch size from 3 to 7, with mean of 5.6.

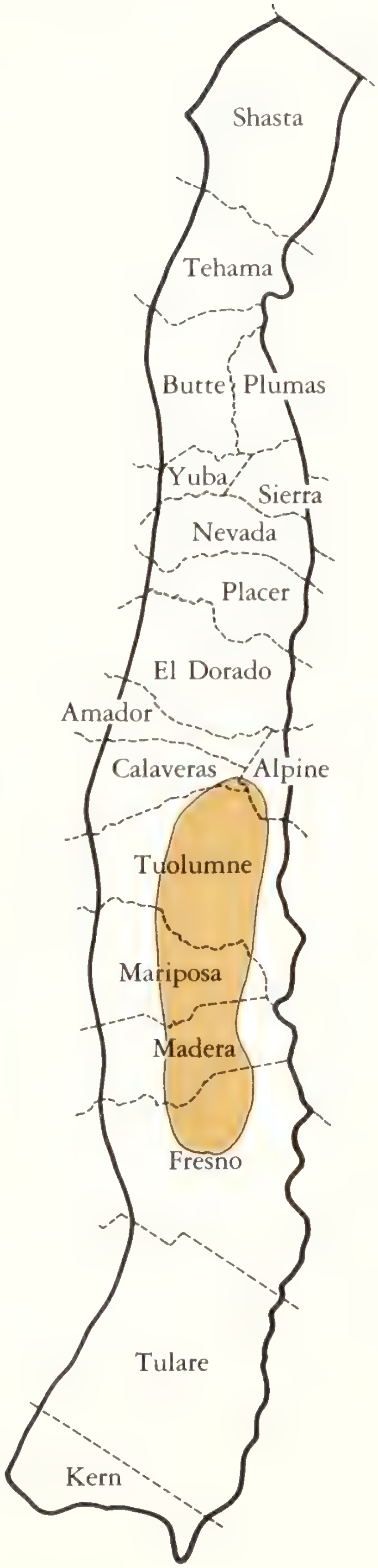
TERRITORY/HOME RANGE: In Iceland, defended only small area around female; average density 2.1 pairs/mi of stream (1.3 pairs/km) (Bengston 1966b).

FOOD HABITS: Eats insects, mollusks, crustaceans, fishes, and some water plants. Food taken from rocky bottoms of swift streams by diving; sometimes tips up to feed under water surface.

OTHER: Reasons for declining population in the Sierra Nevada unknown. Disturbance of wintering habitat along the coast suggested; also dramatic increase in numbers of fishermen and other human visitors to high mountain streams.

REFERENCES: Bengston 1966a, 1966b; Bellrose 1976; Palmer 1976.





Ruddy Duck

B024 *(Oxyura jamaicensis)*

STATUS: No official listed status. Game species. Rare spring and fall migrant and winter visitor.

DISTRIBUTION/HABITAT: Found on shallow ponds or lakes from annual grasslands up to ponderosa pine and black oak woodland types. Prefers ponds with an abundance of submerged aquatic vegetation; avoids ponds surrounded by dense stands of timber.

SPECIAL HABITAT REQUIREMENTS: Ponds, lakes.

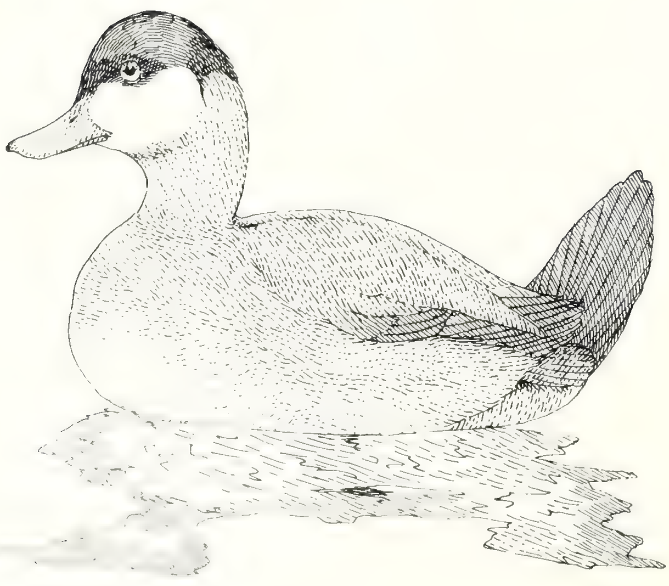
BREEDING: Does not breed in the western Sierra Nevada.

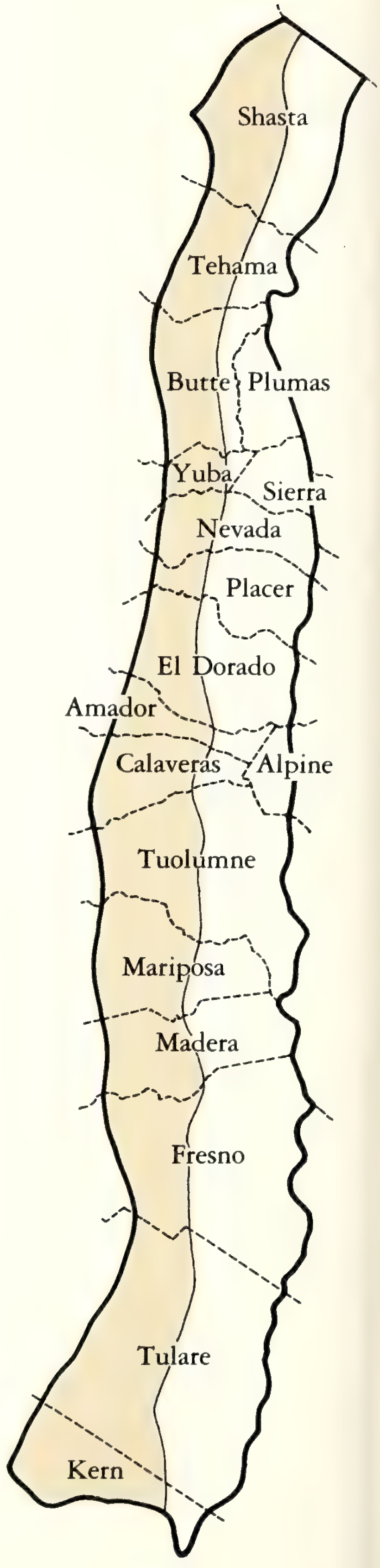
TERRITORY/HOME RANGE: No data on winter home range; not territorial in winter.

FOOD HABITS: Eats pondweeds, sedges, bulrushes, mollusks, and crustaceans. Dives, often to depths of 10 to 20 ft (3.0 to 6.1 m), to feed in the water and on the muddy bottom; sometimes feeds on water surface.

OTHER: Only one spring record located for the western Sierra Nevada: Wilson Lake, Lassen National Park, on March 24, 1927 (Grinnell *et al.* 1930).

REFERENCES: Joyner 1969, Johnsgard 1975b, Bellrose 1976, Palmer 1976.





Hooded Merganser

B025 *(Lophodytes cucullatus)*

STATUS: No official listed status. Game species. Rare fall and spring migrant and winter visitor.

DISTRIBUTION/HABITAT: Frequents ponds and slow-moving streams in timbered sections from blue oak savannah up to ponderosa pine and black oak woodland types. Cited as a possible breeder in the Sierra Nevada (Bellrose 1976), but corroborating evidence not at hand. Latest spring record found April 18 (Gaines 1977).

SPECIAL HABITAT REQUIREMENTS: Ponds, lakes, slow-moving streams, or rivers.

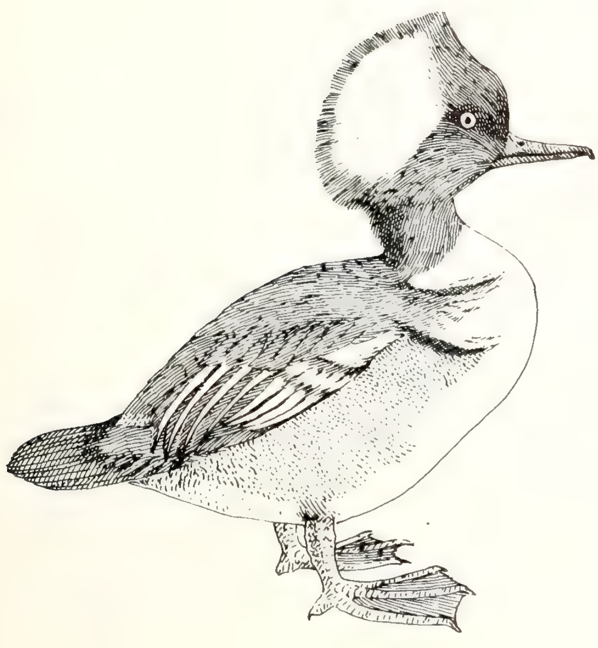
BREEDING: Does not breed in the western Sierra Nevada.

TERRITORY/HOME RANGE: No data on home range; not territorial in winter.

FOOD HABITS: Major food items are fishes, crustaceans, aquatic insects, and frogs. Feeds almost exclusively by diving. Captures food in water or takes from muddy or rocky bottoms of ponds and streams.

OTHER: Susceptible to biological concentration of hard pesticides used in watersheds draining into aquatic habitats.

REFERENCES: Grinnell *et al.* 1918, Johnsgard 1975b, Bellrose 1976, Palmer 1976.



Common Merganser

B026 *(Mergus merganser)*

STATUS: No official listed status. Game species. Fairly common winter visitor and uncommon breeder.

DISTRIBUTION/HABITAT: Breeds along edges of forested lakes and streams from blue oak savannah up to lodgepole pine forests, and from McCloud River in the north to Kern River in the south. Remains through winter on fresh, clear rivers as long as rivers are ice-free.

SPECIAL HABITAT REQUIREMENTS: Ponds, lakes, or slow-moving streams or rivers.

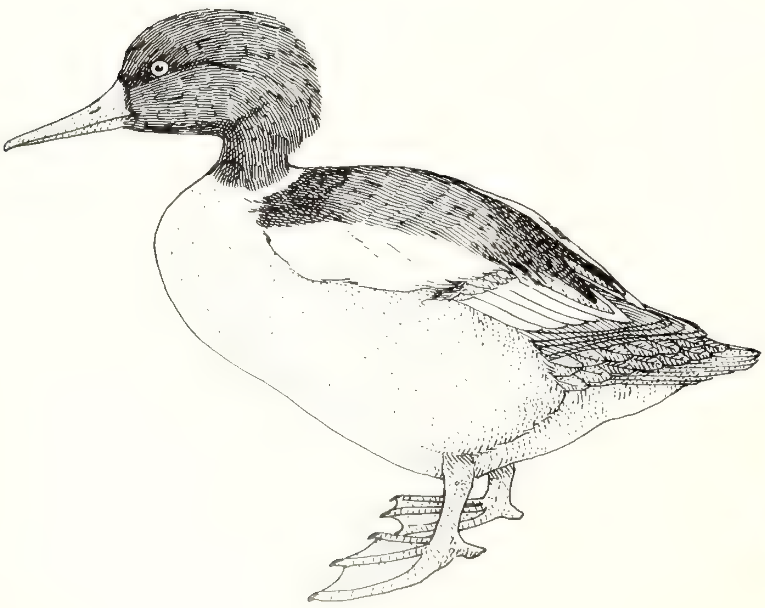
BREEDING: Breeds from early May to early August, with peak from mid-June to mid-July. Usually nests in tree cavity near clear river or stream with many fish. Some nests placed on ground under bushes or boulders; islands preferred for ground nesting. Clutch size from 6 to 12, with mean of 9.4.

TERRITORY/HOME RANGE: No data on territory size. Home ranges generally included 2 to 3 mi (3.2 to 4.8 km) of river (Palmer 1976). Spacing of common mergansers averaged 3.5 mi (5.6 km) apart on coastal streams of northwestern California (Forman 1976).

FOOD HABITS: Feeds on fish, including perch, carp, trout, and salmon. Dives for fish in clear, shallow water.

OTHER: Has been implicated in destruction of fisheries. Conclusions from studies indicate opportunistic foraging on species common and easily captured. Eats primarily nongame fish species, but captures some trout or salmon in areas specifically managed for those species.

REFERENCES: Grinnell *et al.* 1918, Johnsgard 1975b, Bellrose 1976, Palmer 1976.



Turkey Vulture

B027 *(Cathartes aura)*

STATUS: No official listed status. Fairly common breeding bird, less common in winter.

DISTRIBUTION/HABITAT: Breeds mainly in zone of blue oak savannah, digger pine-oak, and chaparral. Ranges to higher altitudes in late summer. In winter, less common and found only at lower altitudes, where requires a roost—either single large tree with open branch-work or section of grove.

SPECIAL HABITAT REQUIREMENTS: Open terrain for foraging.

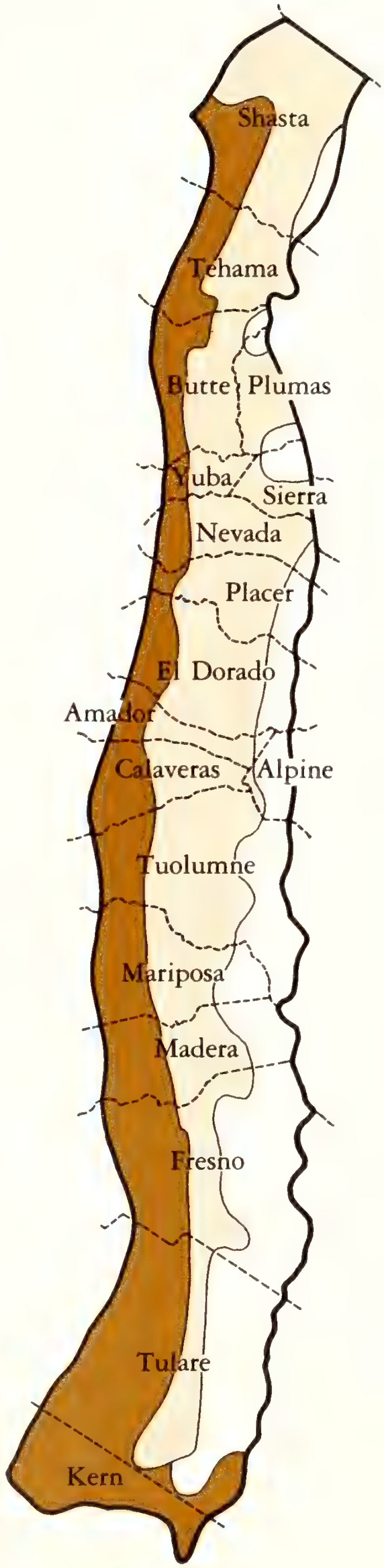
BREEDING: Breeds from early March to late September, with peak from late May to mid-August. Clutch size usually 2 or 3. Nests in well-hidden cavity in cliff face, in rocks or brush on steep hillsides, or in hollow log or stump.

TERRITORY/HOME RANGE: Unknown.

FOOD HABITS: Feeds mainly on carrion; rotting fruits and vegetables, live young birds, and eggs taken rarely. Food taken from ground, but located while soaring and gliding.

OTHER:

REFERENCES: Coles 1944, Brown and Amadon 1968.



California Condor

B028 *(Gymogyps californianus)*

STATUS: On Federal and California Endangered Species Lists. Some non-breeders move north into the western Sierra Nevada in May and remain until late fall.

DISTRIBUTION/HABITAT: Roosts or feeds in any habitat type.

SPECIAL HABITAT REQUIREMENTS: Open terrain for foraging; large trees or cliffs for roosting.

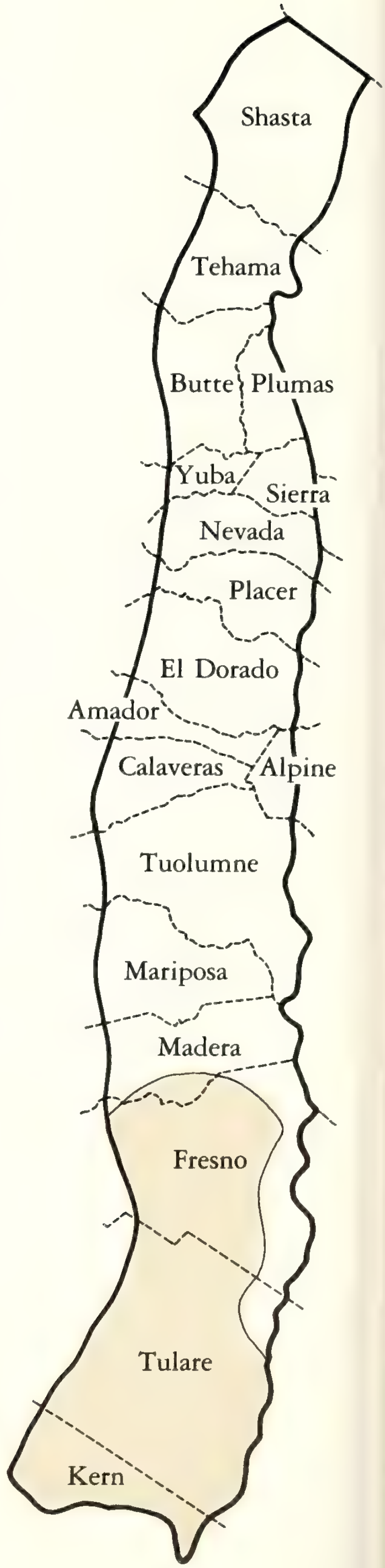
BREEDING: Does not breed in the western Sierra Nevada at present.

TERRITORY/HOME RANGE: Condors fly distance of at least 35 mi (56 km) between roosting and feeding sites (Koford 1953). Not known to be territorial during nonbreeding periods; nesting territoriality not confirmed. Simultaneous use of nests 0.5 mi (0.8 km) apart, where nest defense between adult condors not observed (Koford 1953).

FOOD HABITS: Feeds exclusively on carrion, dead range cattle mainly; also sheep, deer, horses, and ground squirrels. Prefers deer and young calves. Searches for carrion while soaring and gliding; always eats on ground.

OTHER: See Miller *et al.* (1965, p. 49) for management recommendations.

REFERENCES: Koford 1953; Miller *et al.* 1965; Wilbur 1976, 1978; Verner 1978.



White-tailed Kite

B029 *(Elanus leucurus)*

STATUS: No official listed status. Formerly endangered, now fairly common. Range expanded in recent decades. Probably uncommon above 1000 ft (305 m), though literature unclear.

DISTRIBUTION/HABITAT: Restricted to lower elevations; breeds in sites with trees in blue oak savannah, digger pine-oak, and riparian deciduous types. Nests only where voles (*Microtus* spp.) abundant; concentrates in areas with dense populations of small rodents in winter.

SPECIAL HABITAT REQUIREMENTS: Trees with dense canopies for nesting.

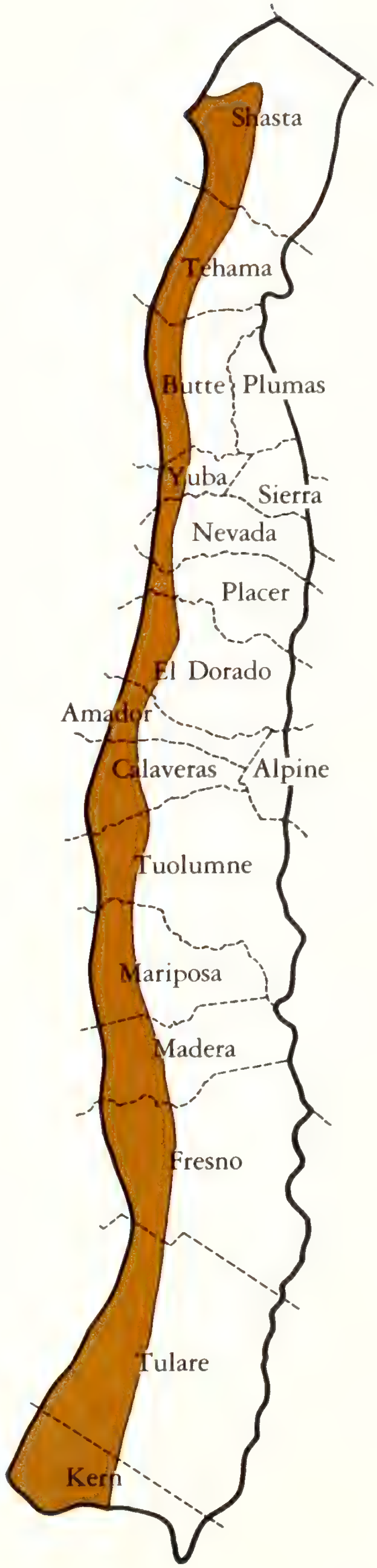
BREEDING: Breeds from early February to late October, with peak from early May to early August. Sometimes rears two broods per season. Nest placed at top of a dense-topped tree of moderate height; nests range in height from 18 to 59 ft (5 to 18 m). Clutch size from 3 to 6, with mean of 4.1.

TERRITORY/HOME RANGE: Nonterritorial in San Diego and Solano Counties (Dixon *et al.* 1957, Stendell 1972). Minimum requirement for breeding pair is 20 acres (8 ha) during a good vole year.

FOOD HABITS: Feeds almost exclusively on diurnal mice captured and eaten on ground. Searches by flying and hovering at less than 100 ft (30 m) above ground; attacks by slow vertical descent.

OTHER: Habitat increased in recent decades by year-round irrigation of agricultural land.

REFERENCES: Dixon *et al.* 1957, Waian and Stendell 1970, Eisenmann 1971.



Goshawk

B030 *(Accipiter gentilis)*

STATUS: No official listed status. Uncommon resident and winter visitor; precise status requires further study.

DISTRIBUTION/HABITAT: Typically breeds in mature stands of conifer forest. Nests sometimes in thicket of medium-aged conifers, with or without aspen interspersed, from mixed-conifer zone up to lodgepole pine type. Prefers stands of intermediate canopy coverage. Remains year-round in breeding areas; during nonbreeding season, some move downslope as far as blue oak savannah.

SPECIAL HABITAT REQUIREMENTS: Water probably needed on breeding territory.

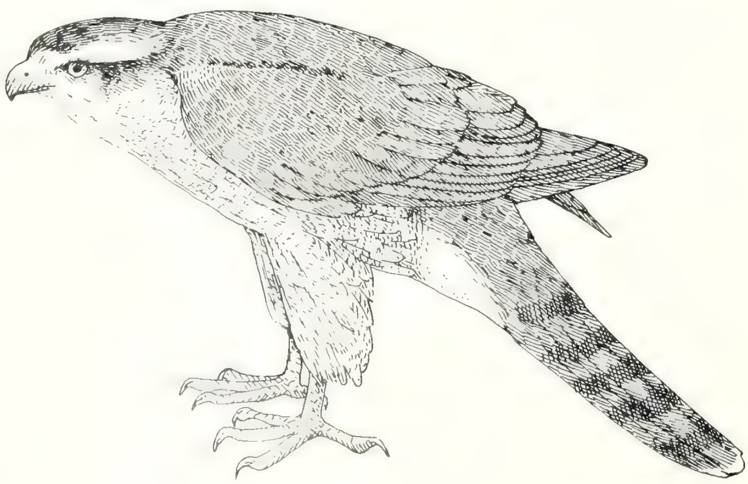
BREEDING: Breeds from mid-March to early September, with peak from early May to mid-July. Nest usually built on a large, horizontal limb within 12 ft (3.7 m) of trunk and from 20 to 80 ft (6.1 to 24 m) above ground, in conifer, and in densest part of stand, usually near meadow or other opening. Clutch size from 1 to 5, with mode of 3.

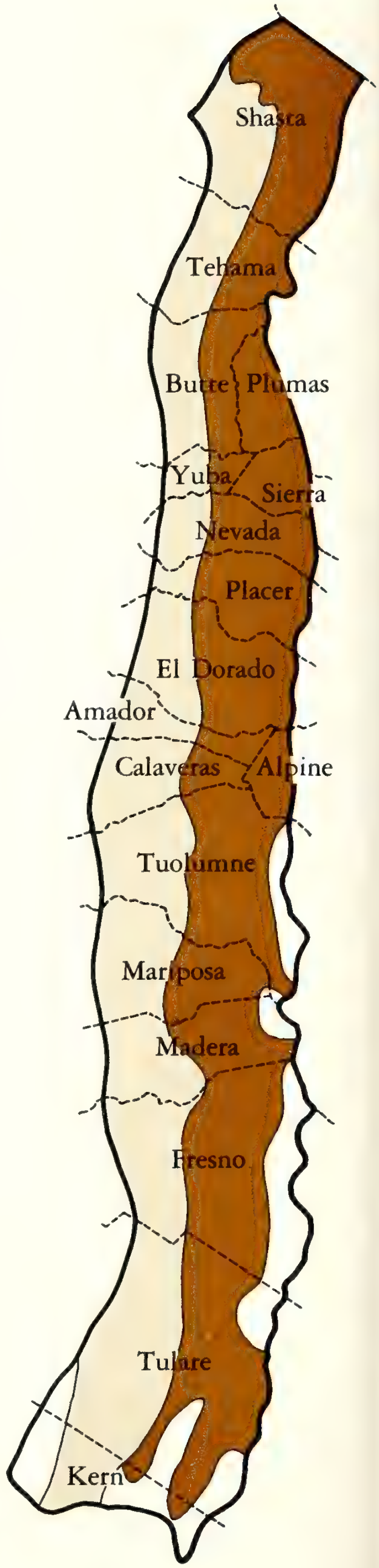
TERRITORY/HOME RANGE: Territory and home range apparently the same. In Wyoming, a single territory studied covered 525 acres (212 ha) (Craighead and Craighead 1956); may range over areas as large as 6 to 15 mi^2 (16 to 39 km^2) (Brown and Amadon 1968). A home range of about 5 mi^2 (13 km^2) estimated in Minnesota (Eng and Gullion 1962). In Oregon, four nests located on 45 mi^2 (117 km^2); mean distance between nests 2.7 mi. (4.3 km) (Reynolds 1978).

FOOD HABITS: Mammals in size range from chickarees to hares comprise 55 percent of diet; birds in size range from robins to grouse, 45 percent of diet. Prey captured on ground, in vegetation, or in air, by using fast searching flight or rapid dash from a perch.

OTHER: Recommended management policies that should be read: Jackman and Scott 1975, p. 28. Most important recommendation suggests leaving 30 acres (12 ha) of undisturbed timber around all known nests. Acreage should include substantial amount of north-facing slope, all prey-plucking sites, and much water course. Wear hard hat in vicinity of nest.

REFERENCES: Schnell 1958, Brown and Amadon 1968, Jackman and Scott 1975, Jones 1979.





Sharp-shinned Hawk

B031 *(Accipiter striatus)*

STATUS: No official listed status; on the Audubon Society Blue List for 1978. Uncommon permanent resident in mid-elevation habitats; seasonal resident in lower and higher areas.

DISTRIBUTION/HABITAT: Breeds in pole to mature tree stages of ponderosa pine, black oak, riparian deciduous, mixed-conifer, and Jeffrey pine types; prefers stands with intermediate to high percent canopy coverage. Moves upslope in summer and fall. Also moves downslope for fall, winter, and spring periods as far as blue oak savannah, occasionally even into annual grasslands for feeding. May be absent from the southern Sierra Nevada.

SPECIAL HABITAT REQUIREMENTS: Trees or shrubs.

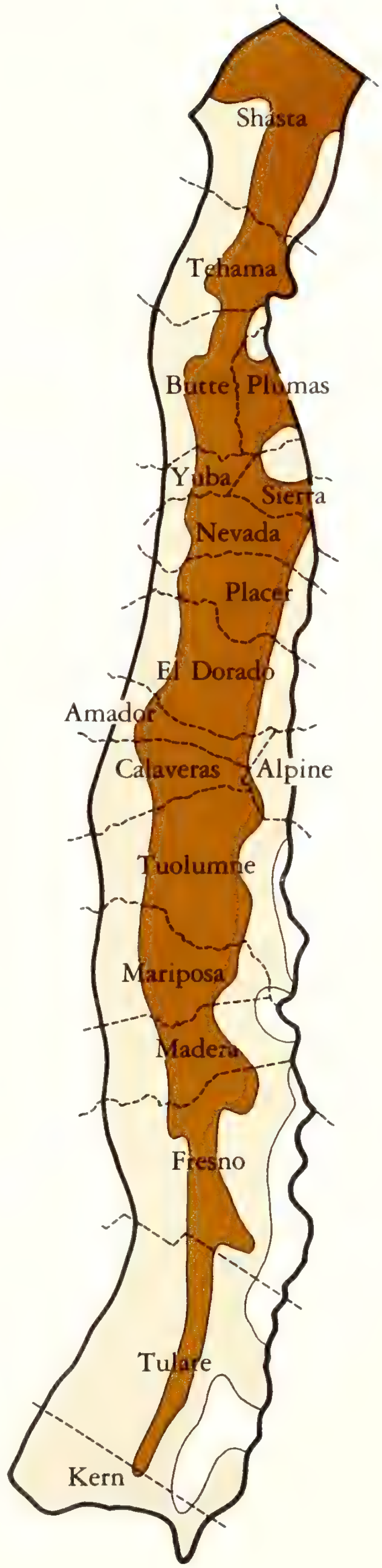
BREEDING: Breeds from early April to late August, with peak from early June to early August. Nests within dense forest canopy, against tree trunk or in crotch of trunk, usually from 6 to 60 ft (2 to 18 m) up; prefers conifers. Clutch size from 3 to 8, usually 4 or 5.

TERRITORY/HOME RANGE: Two home ranges studied in Jackson Hole, Wyoming, covered 160 and 320 acres (65 and 130 ha) (Craighead and Craighead 1956). Apparently, territory and home range the same. In Oregon, four nests located on 45 mi^2 (117 km^2); mean distance between nests 2.7 mi. (4.3 km) (Reynolds 1978).

FOOD HABITS: Small birds make up 97 percent of total diet, small mammals 3 percent. Prey captured on ground, in vegetation, and from air. Hunting involves fast searching flight or rapid dash from concealed perch. Often forages at edges of forest and woodland.

OTHER: Recommended management practices that should be read: Jackman and Scott 1975, p. 45. Most important "A minimum of 10 acres should be preserved around all known nesting trees . . . " North-facing slopes, plucking sites, and water sources should be included.

REFERENCES: Brown and Amadon 1968, Wattel 1973, Jackman and Scott 1975, Jones 1979.



Cooper's Hawk

B032 *(Accipiter cooperi)*

STATUS: No official listed status; on the 1978 Audubon Society Blue List. Rare and apparently declining in the Sierra Nevada, possibly as a result of pesticides used. Status requires further study.

DISTRIBUTION/HABITAT: Breeds from digger pine-oak up to ponderosa pine and black oak woodland zone; prefers dense stands of live oaks or riparian sites. Apparently frequents edge situations. In winter, found in variety of wooded habitats.

SPECIAL HABITAT REQUIREMENTS: Trees with dense canopies for nesting; trees/shrubs or trees/grass-forbs.

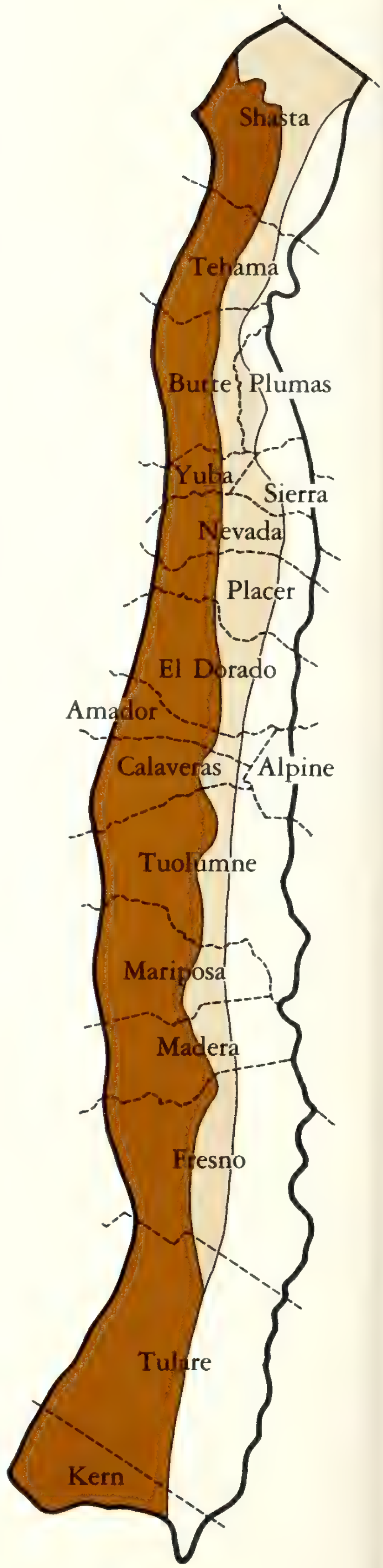
BREEDING: Breeds from early April to late August, with peak from early June to early August. Nests on horizontal branch near trunk, or in an upright crotch 25 to 40 ft (7.6 to 12.2 m) up. Clutch size from 2 to 6, usually 4 or 5.

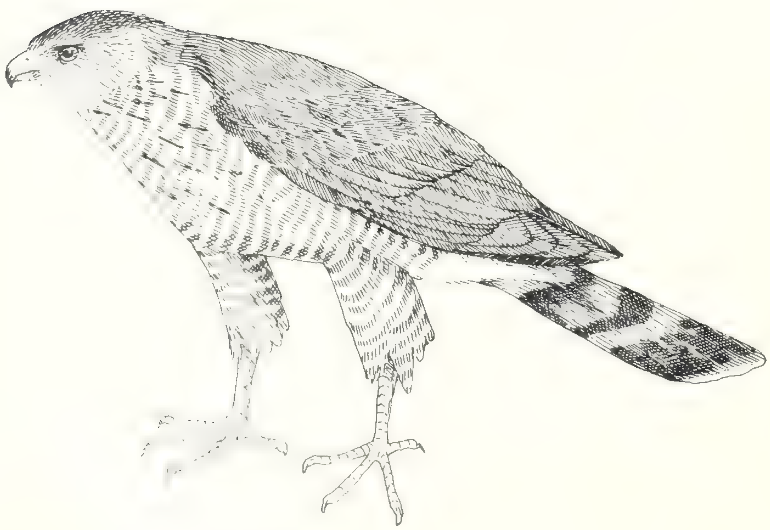
TERRITORY/HOME RANGE: In Michigan, three breeding home ranges varied from 260 to 1000 acres (105 to 404 ha), with mean of 720 acres (291 ha). Territory size appears to be the same (Craighead and Craighead 1956). In 77 territories in California valley and live oak stands, mean distance between nests 1.6 mi (2.6 km) (C. Asay, pers. commun.).

FOOD HABITS: Small- to medium-sized birds make up 82 percent of diet, and small mammals 18 percent. Forages in air, on ground, and in vegetation. Usually chases prey from inconspicuous perch, or searches while in flight.

OTHER: See Jackman and Scott (1975) for management recommendations.

REFERENCES: Craighead and Craighead 1956, Brown and Amadon 1968, Henny and Wight 1972, Jackman and Scott 1975, Jones 1979.





Red-tailed Hawk

B033 *(Buteo jamaicensis)*

STATUS: No official listed status. Common winter resident; breeds in foothills. Some move up to open areas at high elevations in summer and fall.

DISTRIBUTION/HABITAT: Found in most successional stages from blue oak savannah to lodgepole pine and alpine meadows. Activity primarily associated with open canopy areas of blue oak savannah and digger pine-oak types. Prefers habitat where rodents can be seen from air.

SPECIAL HABITAT REQUIREMENTS: Large trees or cliff for nesting and roosting; large openings for foraging.

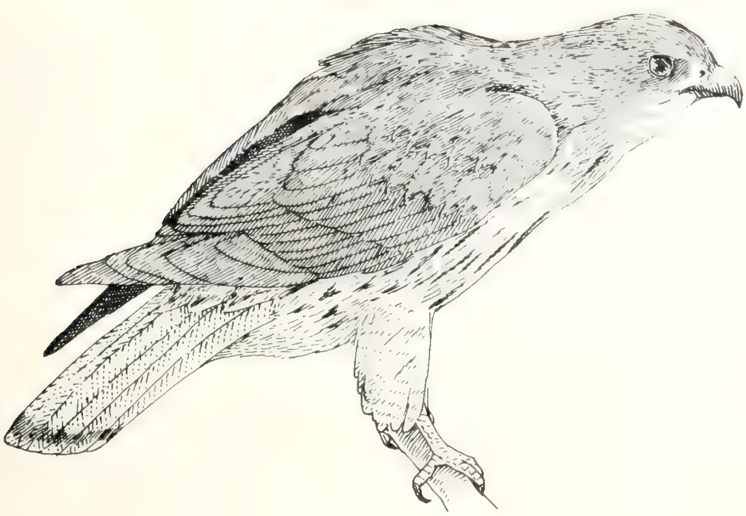
BREEDING: Breeds from late January to early September, with peak from early May to early August. Nests in crotch or fork of tree, usually within 30 to 70 ft (9.1 to 21 m) of ground. Less frequently nests on cliffs. Clutch size from 1 to 4, with 3 most common.

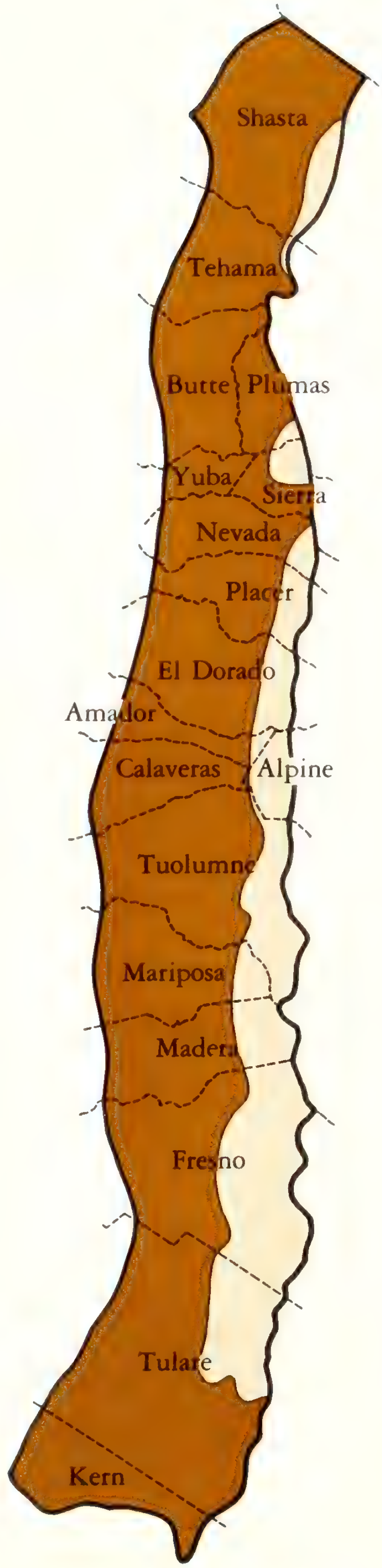
TERRITORY/HOME RANGE: Year-round territory sizes from utilized perch sites in the Sierra foothills, Madera County, roughly estimated (Fitch *et al.* 1946). Estimates ranged from 160 to 400 acres (65 to 162 ha).

FOOD HABITS: Eats mainly small mammals, especially ground squirrels; medium-sized birds and reptiles also taken. Usually swoops to ground from perch or quartering flight.

OTHER:

REFERENCES: Fitch *et al.* 1946, Craighead and Craighead 1956, Luttich *et al.* 1971, Jackman and Scott 1975.





Red-shouldered Hawk

B034 *(Buteo lineatus)*

STATUS: No official listed status; on the Audubon Society Blue List for 1978, though apparently no significant decline in California populations (Wilbur 1973). Uncommon even in suitable habitat in the western Sierra Nevada.

DISTRIBUTION/HABITAT: Resident along Kern River at about 2000 to 3000 ft (610 to 914 m); may be found as vagrant at low elevations throughout the western Sierra Nevada. Breeds only in extensive tracts of riparian deciduous woodland; feeds in grasslands and early successional stages of blue oak savannah and digger pine-oak types.

SPECIAL HABITAT REQUIREMENTS: Large tracts of riparian deciduous woodland for breeding.

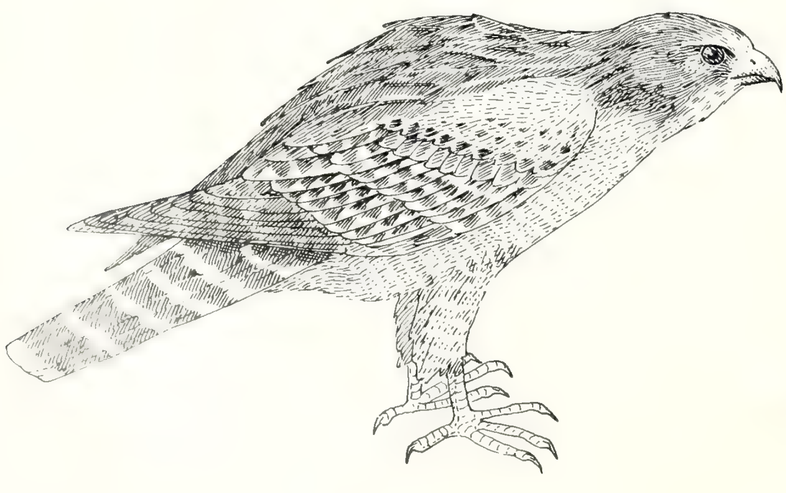
BREEDING: Breeds from early February to mid-July, with peak from mid-April to late June. Nests usually near stream, in branches or crotch of main trunk of large tree, frequently riparian hardwood or eucalyptus. Nest height ranges from 28 to 77 ft (8.5 to 23 m), with average of 50 ft (15 m). Clutch size 1 to 4, with mean of about 3.

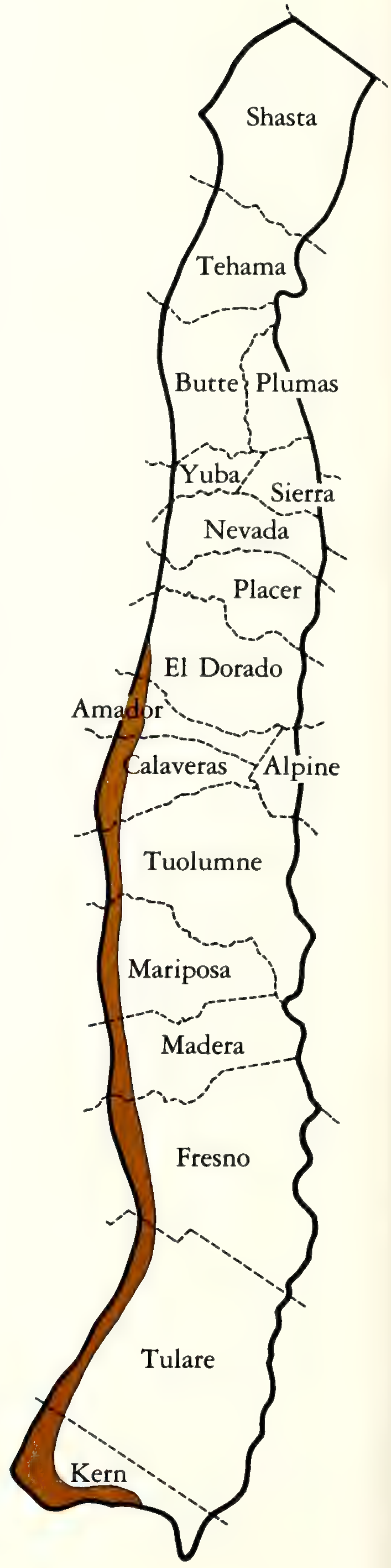
TERRITORY/HOME RANGE: Breeding territory and home range the same. Fifty-one breeding territories studied in a Maryland coastal plain, riparian woodland averaged 480 acres (194 ha) in size (Stewart 1949). Average breeding home range size in Michigan observed as 156 acres (63 ha), with a range of 19 to 384 acres (7.7 to 155 ha) (n = 42) (Craighead and Craighead 1956). Winter home ranges reported from 313 to 1242 acres (127 to 503 ha), with mean of 838 acres (339 ha) (Craighead and Craighead 1956).

FOOD HABITS: Highly varied diet includes rabbits, smaller mammals, small birds, amphibians, reptiles, and some insects. Usually captures prey on the ground. Searches for food from perch on snag, stub, or post.

OTHER: Continued presence in the western Sierra Nevada depends on maintenance of extensive tracts of riparian deciduous vegetation.

REFERENCES: Stewart 1949, Brown and Amadon 1968, Wiley 1975.





Swainson's Hawk

B035 *(Buteo swainsoni)*

STATUS: No official listed status; on the 1978 Audubon Society Blue List, as serious declines noted in all western regions. Uncommon migrant and summer resident; present breeding status in the Sierra Nevada questionable.

DISTRIBUTION/HABITAT: Breeds (currently?) in blue oak savannahs and digger pine-oak woodlands; prefers stands with few trees. Occurrence in high elevation meadows uncommon, probably representing local movements of birds from east side of the Sierra Nevada crest.

SPECIAL HABITAT REQUIREMENTS:

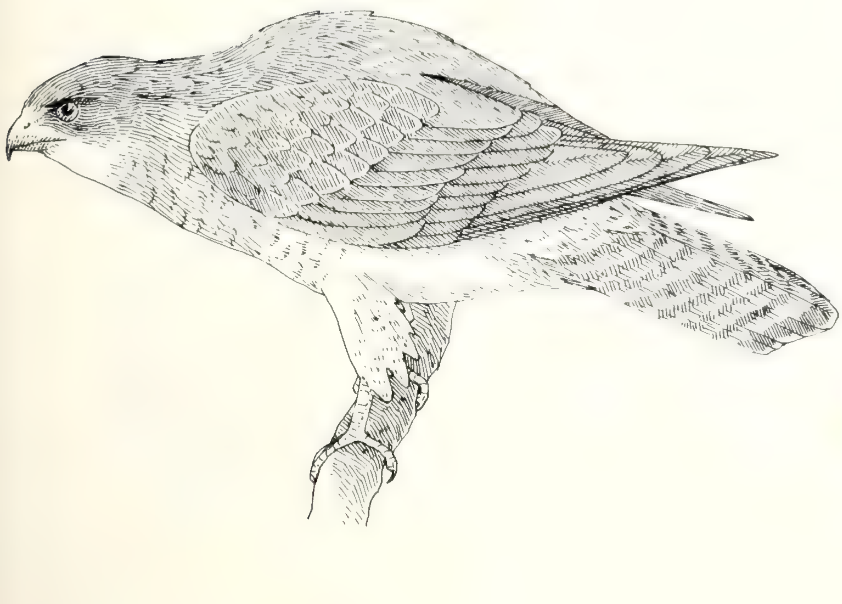
BREEDING: Breeds from late March to mid-August, with peak from late May to late July. Usually nests in a live or dead tree, within 25 ft (7.6 m) of the ground; occasionally on cut banks or low cliffs. Clutch size from 2 to 4, with mode of 2.

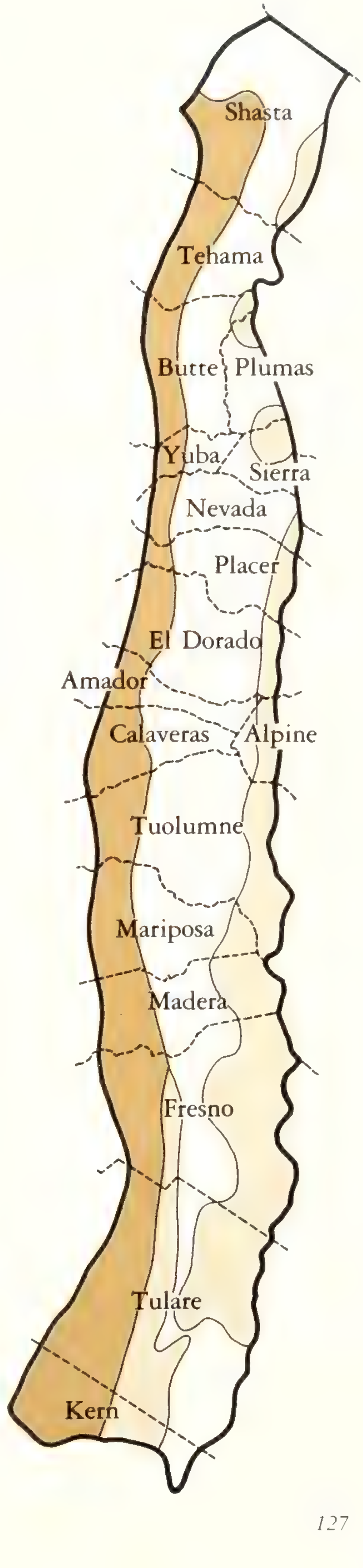
TERRITORY/HOME RANGE: Three home ranges in Utah ranged from 1.2 to 2.1 mi^2 (3.1 to 5.4 km^2), with a mean of 1.6 mi^2 (4.1 km^2) (Smith and Murphy 1973). Average home range of 1.0 mi^2 (2.6 km^2) reported in Wyoming (Craighead and Craighead 1956). Territory and home range considered to be about the same.

FOOD HABITS: Eats mostly small mammals; birds, reptiles, and large insects also eaten. Pounces on prey on ground from a low, searching flight.

OTHER:

RERERENCES: Bowles and Decker 1934, Brown and Amadon 1968, Smith and Murphy 1973, Dunkle 1977.





Golden Eagle

B036 (*Aquila chrysaetos*)

STATUS: No official listed status. Uncommon resident; ranges widely over various terrains.

DISTRIBUTION/HABITAT: Found in annual grassland to above timberline in all successional stages. Favors grass/forb, shrub/sapling, and open-canopied young woodlands of blue oak. In late summer, often seen above timberline. Main requirements a good nest site, open country, and dependable food supply.

SPECIAL HABITAT REQUIREMENTS: Cliffs or scattered large trees.

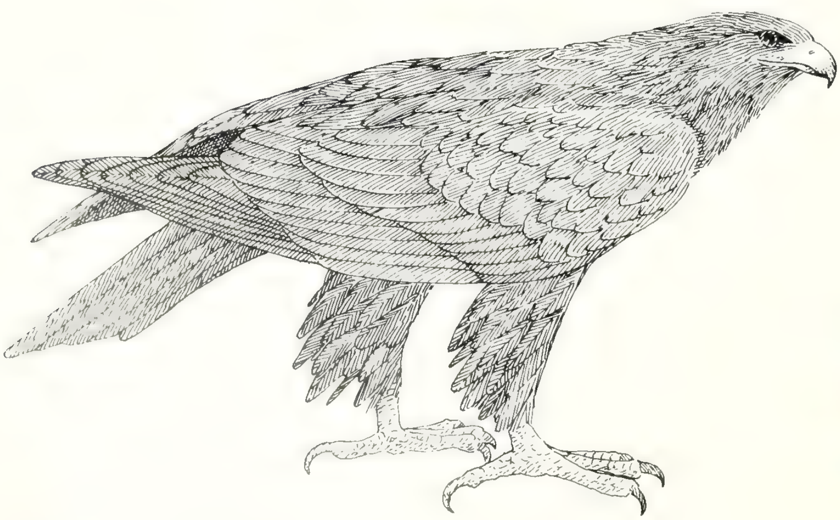
BREEDING: Breeds from mid-January to late September, with peak between late April and August. Nests usually on cliff ledge with commanding view; also in large trees, both living and dead, from 10 to 100 ft (3 to 30 m) above ground. Clutch size from 1 to 3, with 2 most common.

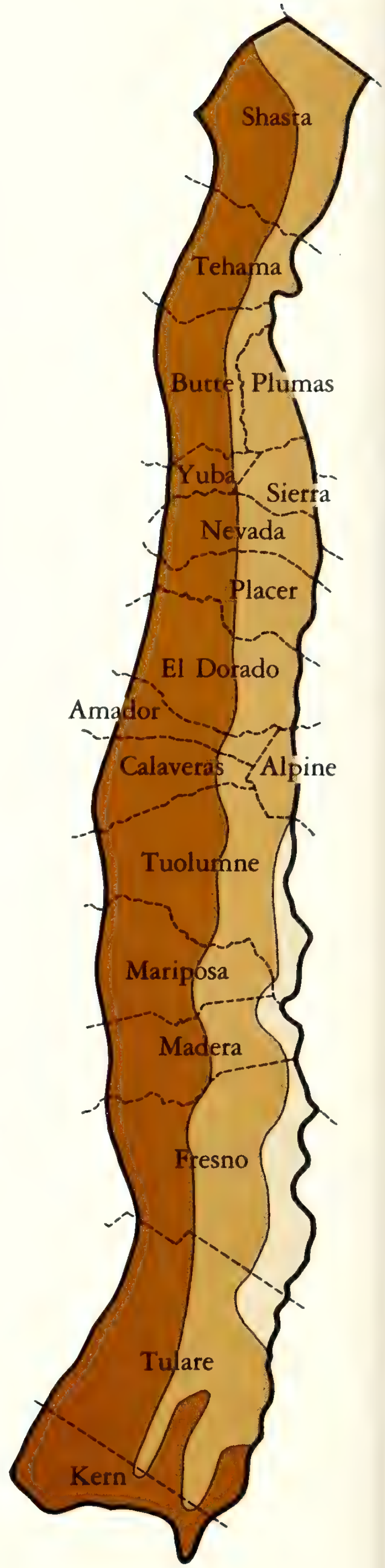
TERRITORY/HOME RANGE: In San Diego County, 27 year-round home ranges varied from 19 to 59 mi^2 (49 to 153 km^2) and averaged 36 mi^2 (93 km^2) (Dixon 1937). Territory size found to be the same. In Utah, six breeding home ranges varied from 6.6 to 11.8 mi^2 (17 to 31 km^2) and averaged 9 mi^2 (23 km^2) (Smith and Murphy 1973). Territory size the same.

FOOD HABITS: Eats mainly lagomorphs and rodents; also eats other mammals, birds, and carrion. Forages usually on ground. Searches by soaring at 100 to 300 ft (30 to 91 m) or by quartering at about 25 ft (7.6 m). Dives on prey.

OTHER: No data on roost requirements.

REFERENCES: Dixon 1937, Smith and Murphy 1973, Thelander 1974, Beecham and Kochert 1975, Jackman and Scott 1975.





Bald Eagle

B037 *(Haliaeetus leucocephalus)*

STATUS: Listed as Endangered on both Federal and State lists.

DISTRIBUTION/HABITAT: Nests in Shasta, Plumas, and Butte Counties on west slope of the Sierra Nevada. Occassionally observed from October to April in all types of habitat throughout the Sierra Nevada. Primarily associated with young or mature forests of varying canopy closure of ponderosa through mixed-conifer types, but can be found in all successional stages from blue oak savannah to lodgepole pine types. Presence at higher elevations in winter depends on open water and fish available for feeding.

SPECIAL HABITAT REQUIREMENTS: Large lake, stream, or river; large trees for nesting; low human disturbance.

BREEDING: Breeds from early February to early Setpember, with peak from mid-March to late June. Nests usually in overstory ponderosa or sugar pine with foliage shading nest, within 0.5 mi (0.8 km) of large body of water, and with low human disturbance. Nest height above ground ranges from 60 to 200 ft (18 to 61 m), usually 75 to 125 ft (23 to 38 m). Total canopy closure in timber stand usually less than 40 percent (R. Lehman, pers. commun.). Clutch size from 1 to 3, with 1 or 2 most common.

TERRITORY/HOME RANGE: No data available on home range. Territory size for 14 breeding territories in Alaska varied from 28 to 111 acres (11 to 45 ha), and averaged 57 acres (23 ha) (Hensel and Troyer 1964).

FOOD HABITS: Eats mainly fish (live and dead); also carrion, water birds, and mammals. Forages on water surface and ground by swooping from perch or air.

OTHER: Only eight active nests on west slope found in 1972-73, all in Shasta and Butte Counties (Thelander 1973). In 1979, 18 active nests found, 16 in Shasta and one each in Plumas and Butte Counties (R. Lehman, pers. commun.). California breeding population probably stable (R. Lehman, pers. commun.).

REFERENCES: Hensel and Troyer 1964, Snow 1973, Thelander 1973.

Marsh Hawk

B038 *(Circus cyaneus)*

STATUS: No official listed status; on the 1978 Audubon Society Blue List, though apparently not declining in the western Sierra Nevada. Uncommon breeding resident of the Central Valley; found at much higher elevations in late summer and fall.

DISTRIBUTION/HABITAT: Found in grass/forb stages from annual grasslands to lodgepole pine and alpine meadows. Breeds in Central Valley with no evidence of regular breeding above 1000 ft (305 m). Both residents and migrants from north found up to 10,000 ft (3050 m) in the Sierra Nevada in late summer and fall. Present at lower elevations at least until April.

SPECIAL HABITAT REQUIREMENTS:

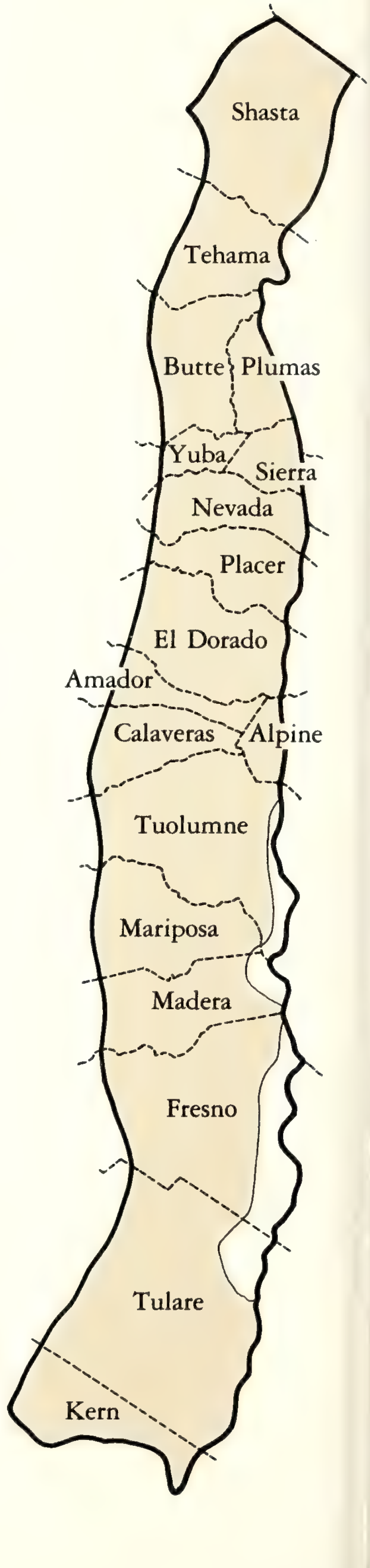
BREEDING: Does not breed regularly on west slope of the Sierra Nevada.

TERRITORY/HOME RANGE: Winter home range in Michigan varied from 30 to 640 acres (12 to 260 ha). Hunting range may extend 5.5 mi (8.8 km) from roost (Craighead and Craighead 1956).

FOOD HABITS: Eats mainly small mammals and birds. Forages on ground, with pouncing from systematic quartering flight at 10 to 30 ft (3 to 9 m) above ground.

OTHER:

REFERENCES: Hammond and Henry 1949, Craighead and Craighead 1956, Brown and Amadon 1968, Hamerstrom 1969.



Osprey

B039 *(Pandion haliaetus)*

STATUS: No official listed status; on the 1978 Audubon Society Blue List. Declined in recent years, probably because of pesticides used and human disturbance.

DISTRIBUTION/HABITAT: Found from annual grasslands through lodgepole pine in association with riparian habitat or lakesides, but primarily in ponderosa pine through mixed-conifer types. Migrates through west slope in spring and fall; in the western Sierra Nevada, apparently breeds only in Shasta County. Not regularly present in winter.

SPECIAL HABITAT REQUIREMENTS: Lakes, rivers for feeding; large trees or cliffs for nesting.

BREEDING: Breeds from early April to early September, with peak from early June to late August. Nests in top of tree, live or dead, 8 to 160 ft (2.4 to 49 m) tall, usually with broad, flat top, within 6 mi (9.6 km) of large lake or river with adequate supply of fish. Clutch size from 1 to 4, with 3 most common.

TERRITORY/HOME RANGE: Range up to 6 mi (9.6 km) from nest to hunting areas (a lake) (Garber 1972). No data available on territory size, but nests in colonies with high density.

FOOD HABITS: Hunts in lake or large river. Eats fish that swim at or near water surface. Searches from high perch or from flight, and dives at fish.

OTHER:

REFERENCES: Koplin 1971, Garber 1972, Jackman and Scott 1975.

Prairie Falcon

B040 *(Falco mexicanus)*

STATUS: No official listed status; on the 1978 Audubon Society Blue List. Rare on west slopes; being reduced in numbers probably because of nest robbing by humans, vertebrate control programs killing its prey, and possibly use of pesticides.

DISTRIBUTION/HABITAT: Ranges from annual grasslands through alpine meadows. Primarily associated with perennial grasslands, lodgepole pine of varying canopy closures, and alpine meadows. Ranges above treeline in late summer, winters at lower elevations.

SPECIAL HABITAT REQUIREMENTS: Open terrain for foraging; cliffs for nesting.

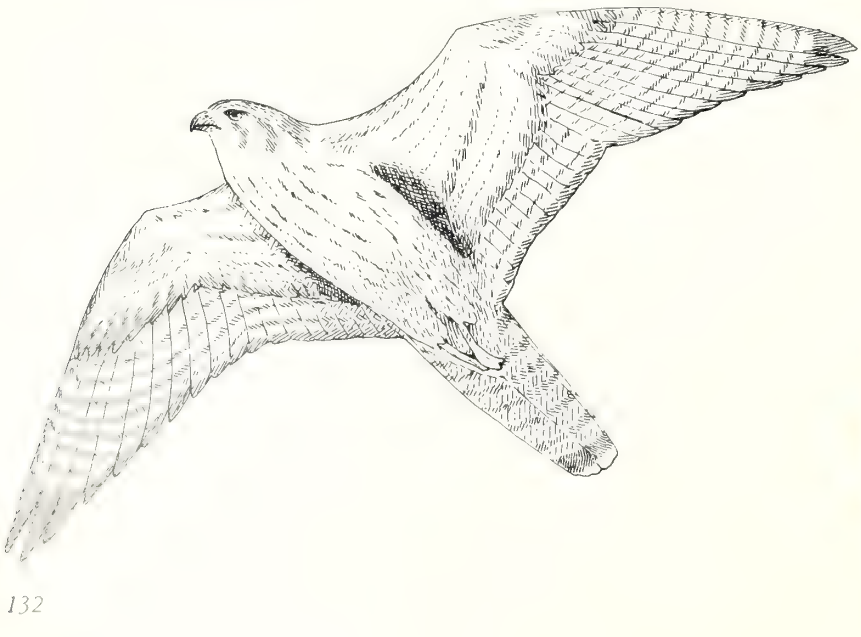
BREEDING: Breeds from mid-February to mid-September, with peak from early May to early August. Formerly would breed mostly below coniferous forests; now most remaining pairs breed at higher altitudes. Nests always on cliff 20 to 400 ft (6.1 to 122 m) high with shelter ledge overlooking large open area. Clutch size from 3 to 6, with 5 most common. A 1971-72 survey of nesting sites within 48 mi (30 km) of the Central Valley found 32 of 33 traditional sites unoccupied (Garrett and Mitchell 1973).

TERRITORY/HOME RANGE: In Wyoming, home range of one breeding pair was 10 mi^2 (26 km^2) (Craighead and Craighead 1956). In Utah, two breeding territories were 2.2 and 2.5 mi^2 (5.7 and 6.5 km^2) in size (Smith and Murphy 1973). In northern Colorado, winter ranges (maximum distance between observation points of marked birds) averaged 3.8 mi (6.1 km) for males and 7.2 mi (11.5 km) for females; maximum range was 12.1 mi (19.4 km) for one female (Enderson 1964).

FOOD HABITS: Eats small mammals and small and medium-sized birds. Forages on ground and in air, involving either a shallow dive from a perch, with rapid pursuit, or a dive from searching flight 50 to 300 ft (15 to 91 m) high.

OTHER:

REFERENCES: Craighead and Craighead 1956, Enderson 1964, Garrett and Mitchell 1973, Smith and Murphy 1973, Snow 1974.



Peregrine Falcon

B041 *(Falco peregrinus)*

STATUS: An Endangered species on both Federal and State lists. Populations declining in recent years because of habitat loss, pesticides, and human disturbance, including nest robbing. Transients in the western Sierra Nevada in spring and fall; not present in winter.

DISTRIBUTION/HABITAT: Found from annual grassland through lodgepole pine, in all successional stages. Nests from digger pine-oak upwards, but prefers low to middle elevations.

SPECIAL HABITAT REQUIREMENTS: Cliffs for nesting and perching; nearby lake or river.

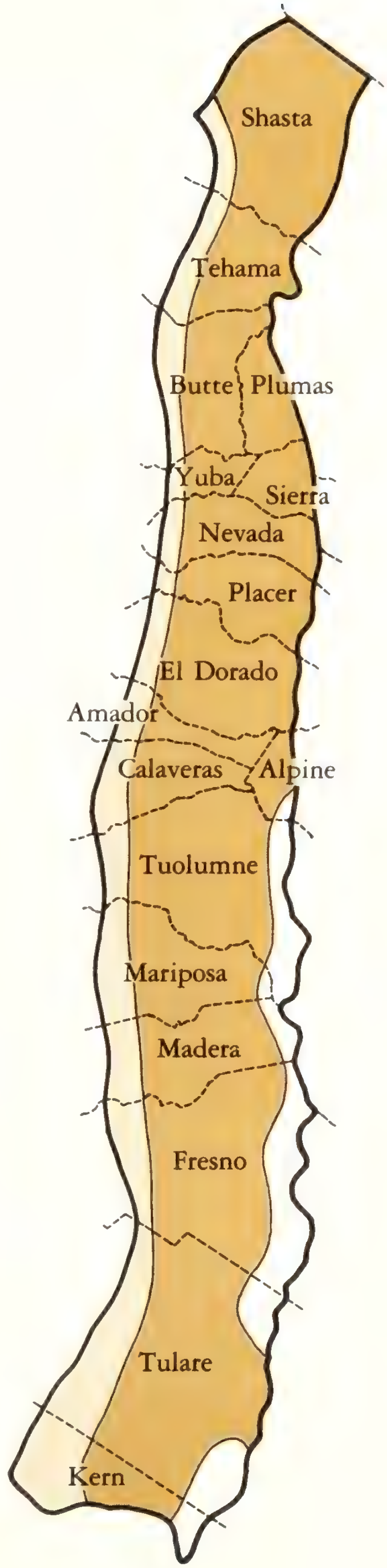
BREEDING: Breeds from early March through late August, with peak from early May to late June. Only one probable breeding site found in the Sierra Nevada, but believed several yet undiscovered (Thelander 1975, 1976). Nests in pothole or ledge on cliff, usually with commanding view. Clutch size in southern California has mean of 3.58, with standard error of 0.72.

TERRITORY/HOME RANGE: In inland habitats in California, breeding sites range from about 3 to 7.5 mi (5 to 12 km) apart (D. Harlow, pers. commun.). In Alaska, breeding territories had minimum radius around nest of about 300 ft (91 m); some birds attacked others up to 1 mi (1.6 km) from the nest (Cade 1960). No nests closer together than 0.25 mi (0.4 km). In Great Britain, home range varied from 17 to 25 mi^2 (44 to 65 km^2) averaging 20.1 mi^2 (52 km^2) (Brown and Amadon 1968). In Utah, species foraged in areas from 0.2 to 18.6 mi (0.32 to 29.8 km) from their nest, with average of 7.6 mi (12.2 km) (n = 19) (Porter and White 1973). In Alaska, breeding male followed by helicopter covered foraging range of 120 mi^2 (290 km^2) (C. White, pers. commun.).

FOOD HABITS: Inland birds in California eat primarily band-tailed pigeons, woodpeckers, and jays, usually taken in air (D. Harlow, pers. commun.). Search from high, exposed perch, with a chase and dive from above.

OTHER:

REFERENCES: Cade 1960; Brown and Amadon 1968; Hickey and Anderson 1969; Snow 1972; Thelander 1975, 1976.



Merlin

B042 *(Falco columbarius)*

STATUS: No official listed status; on the 1978 Audubon Society Blue List. Rare migrant and winter visitor from late September to May.

DISTRIBUTION/HABITAT: Found in fall, winter, and spring from annual grasslands up to ponderosa pine and black oak woodland zone. Prefers open country, sometimes found in early successional stages. Often nomadic in winter, remaining in areas with abundant prey.

SPECIAL HABITAT REQUIREMENTS:

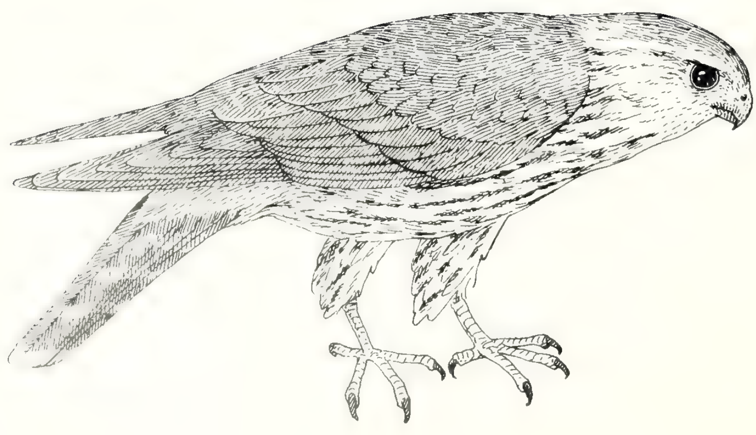
BREEDING: Nonbreeder in the western Sierra Nevada.

TERRITORY/HOME RANGE: No data on home range; nonterritorial in the western Sierra Nevada.

FOOD HABITS: Eats primarily small birds; also eats small mammals and insects. Captures food on ground, also takes some in air. Searches while flying rapidly at low altitude, attacking with short dash or dive from above.

OTHER:

REFERENCES: Craighead and Craighead 1940, Brown and Amadon 1968, Trimble 1975.



American Kestrel

B043 *(Falco sparverius)*

STATUS: No official listed status. Common resident.

DISTRIBUTION/HABITAT: Ranges up to alpine zone, in mountain meadows, and other open areas in late summer and fall, but winters at lower elevations. Prefers large tree stage with 40 to 70 percent crown closure of blue oak savannah and digger pine-oak types for breeding. Pole to medium tree stages of same closure range also attractive, but will use all other successional stages.

SPECIAL HABITAT REQUIREMENTS: Nest cavities in trees or earthen bank; elevated perches; open terrain.

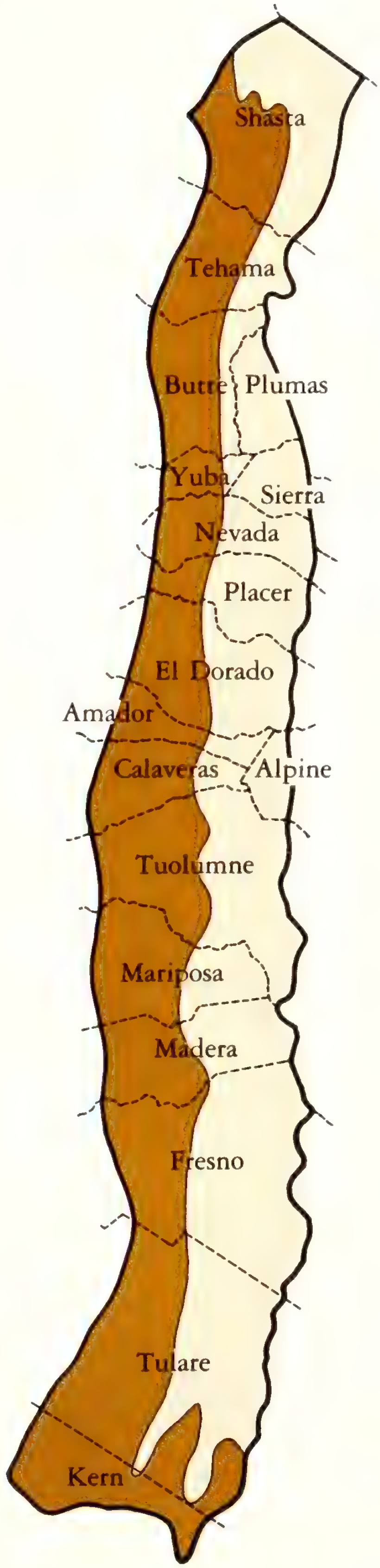
BREEDING: Breeds from early April to early September, with peak between early June and late August. Nests in large woodpecker hole, natural tree cavity, cavity in cliff or earth bank, or magpie nest, from 7 to 81 ft (2.1 to 25 m) above ground. Clutch size from 3 to 7 nationwide, with 4 most common in the Sierra Nevada.

TERRITORY/HOME RANGE: On east slope of the Sierra Nevada, prebreeding home ranges were about double the size of defended breeding territories, which averaged 275 acres (111 ha) for 32 sites (Balgooyen 1976). In southern California, defended only the immediate nest site (Cade 1955). In Ohio, winter territories averaged 375 acres (152 ha), with maximum of 1125 acres (455 ha) (Mills 1975).

FOOD HABITS: Feeds on insects, reptiles, small mammals, and small birds usually on or just above ground. Dives from a perch; sometimes will hover or hawk insects.

OTHER:

REFERENCES: Grinnell and Miller 1944, Cade 1955, Enderson 1960, Brown and Amadon 1968, Balgooyen 1976.



Blue Grouse

B044 *(Dendragapus obscurus)*

STATUS: No official listed status. Game species. Locally common resident in the Sierra Nevada.

DISTRIBUTION/HABITAT: Ranges from ponderosa pine through lodgepole pine and alpine meadows. Primarily found breeding in open-canopied, large tree and medium tree stages of mixed-conifer through red fir types. Complex habitat requirements. Breeds on open or partly brushy slopes with adjacent stands of dense-foliaged conifers, usually true firs, used for roosting and hooting. After breeding, disperses up- and downslope, foraging in open habitats. Most move to high elevation, dense-foliaged conifers for winter but evidence inconclusive for the Sierra Nevada. A few populations do not move up.

SPECIAL HABITAT REQUIREMENTS: Medium to large forest openings; shrubs/grass-forbs.

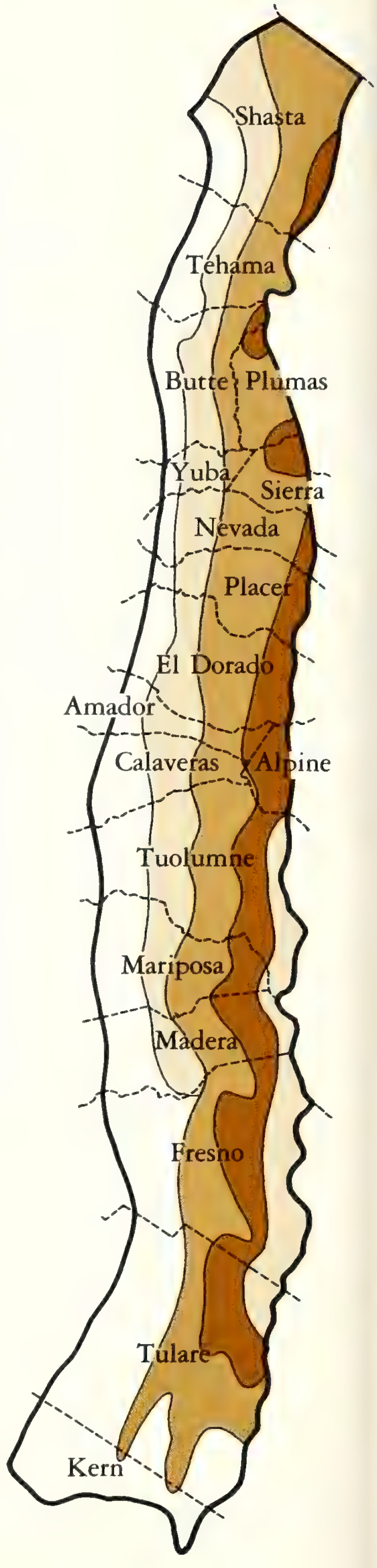
BREEDING: Breeds from early April to September, with peak from mid-May to mid-July. Nests on well-drained ground, often partly concealed by brush, low tree branches, or low cover. Clutch size from 6 to 10, with 7 to 8 most common. Young remain with mother through fall migration; brooding of young rarely continues past mid-July; not known when young gain independence.

TERRITORY/HOME RANGE: In Montana, summer home ranges of broods varied from 1320 to 3960 ft (400 to 1210 m) in diameter (Mussehl 1960). In British Columbia, territory size for a low-density population ranged from 3 to 11 acres (1.2 to 4.5 ha), but varied in a high-density population from 1 to 2 acres (0.4 to 0.8 ha), with a mean of 1.5 acres (0.6 ha) (Bendell and Elliott 1967). In Alberta, mean territory size was 1.5 acres (0.6 ha), with a range from 0.55 to 2.25 acres (0.22 to 0.9 ha) (Boag 1966); breeding season home ranges of 15 marked females averaged 43 acres (17.4 ha).

FOOD HABITS: Feeds mainly on needles, buds, and pollen cones of conifers taken by gleaning, grazing, and browsing on conifers. In winter eats mainly seeds, berries, foliage, and insects.

OTHER:

REFERENCES: Hoffman 1956; Mussehl 1960; Bendell and Elliott 1966, 1967; Johnsgard 1973; Jackman and Scott 1975.



White-tailed Ptarmigan

B045 *(Lagopus leucurus)*

STATUS: No official listed status. Introduced at Mono Pass in 1971-72 by California Department of Fish and Game; apparently breeding successfully and expanding their range.

DISTRIBUTION/HABITAT: Breeds in alpine meadows strewn with rocks and boulders; in winter, some may move downslope into early successional stages of lodgepole pine forest.

SPECIAL HABITAT REQUIREMENTS: Rock outcrops; probably shrubs/grass-forbs.

BREEDING: Breeds from late May to September, with peak from early June to late July in parts of range outside of California; no California data available. Nests on the ground in variety of sites; must be near meadows and accessible brooding grounds having short vegetation, and at least 50 percent rock cover. Lays from 3 to 9 eggs per set, usually 5 or 6.

TERRITORY/HOME RANGE: No data on home range. Breeding territories of 16 to 47 acres (6.4 to 18.8 ha), with mean of 36 acres (14.4 ha) reported in the Colorado Rockies (Schmidt 1969).

FOOD HABITS: Feeds on new shoots, leaves, flowers, seeds, and fruits, especially of willows in spring and summer. Eats buds and twigs of willows and some alder catkins in winter. Chicks eat mainly invertebrates. Gleans and grazes food from ground and low plants.

OTHER:

REFERENCES: Choate 1963, Johnsgard 1975a, Gaines 1977.

California Quail

B046 *(Lophortyx californicus)*

STATUS: No official listed status. Game species. Common resident on west slope.

DISTRIBUTION/HABITAT: Primarily found in brush/seedling/sapling stage of blue oak savannah through chaparral. Ranges from annual grasslands through black oak woodlands in open-canopied situations.

SPECIAL HABITAT REQUIREMENTS: Shrubs/grass-forbs; water in dry season.

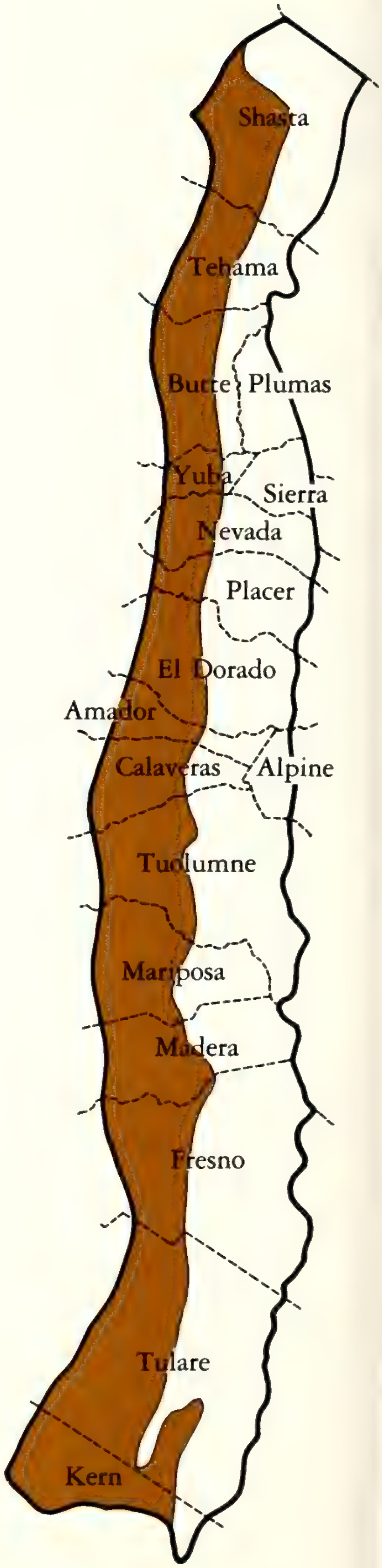
BREEDING: Breeds from early April to mid-September, with peak from early June to late July. Nests on ground usually under cover of brush, logs, rocks, or herbaceous vegetation. Clutch size from 12 to 16, with 14 most common. Young remain with parents through winter; not known when young become independent.

TERRITORY/HOME RANGE: Breeding home range varied from 12 to 25 acres (5 to 10 ha), with winter range from 17 to 45 acres (7 to 18 ha) (Emlen 1939). Only territory known used for crowing by unmated males; size not known. Mated males defended area immediately surrounding mate (Sumner 1935, Genelly 1955).

FOOD HABITS: Feeds on green vegetation and seeds, particularly legumes; also on grains, fruits, and insects by foraging on ground or low vegetation. Scratches, grazes, and jumps for blossoms, seeds, and fruits. In Madera County, a detailed study of 260 young of the year, from June through October, 1973 and 1974, showed food by volume to be 93.3 percent seeds (mostly legumes and other forbs), 5.5 percent insect fragments, 0.8 percent leafage, and 0.4 percent plant galls (Newman 1978).

OTHER:

REFERENCES: Sumner 1935, Raitt 1960, Johnsgard 1973, Leopold 1977.



Mountain Quail

B047 *(Oreortyx pictus)*

STATUS: No official listed status. Game species. Common on west slopes of the Sierra Nevada, with conspicuous altitudinal migration.

DISTRIBUTION/HABITAT: Breeds from chaparral zone up to lodgepole pine forests; prefers stands with much shrubbery and low percent canopy cover. Migrates out of high country; found in winter from ponderosa pine and black oak woodland zones down to digger pine-oak type.

SPECIAL HABITAT REQUIREMENTS: Shrubs/grass-forbs; water in breeding season.

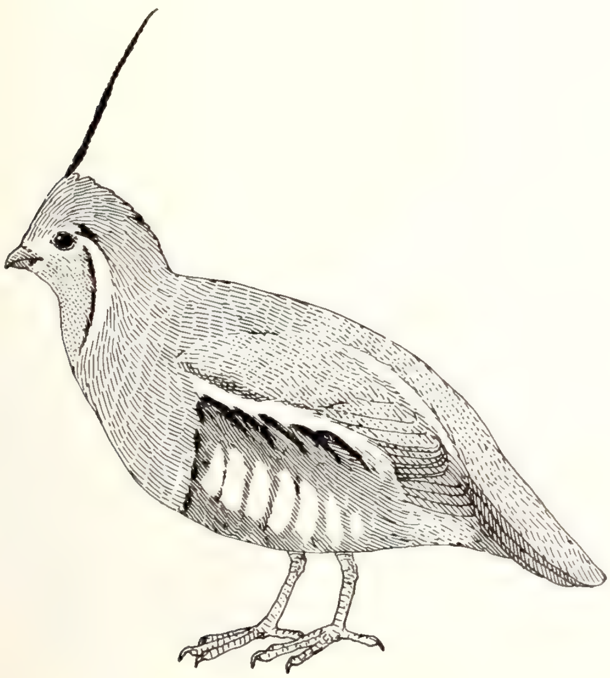
BREEDING: Breeds from mid-April to September, with peak from late June to early August. Nests on ground, under cover of large rock, log, bush, or clump of grass. Clutch size from 6 to 15, with mean of 9. Young usually remain with parents through winter, forming small coveys averaging 7 individuals. Not known when young become independent.

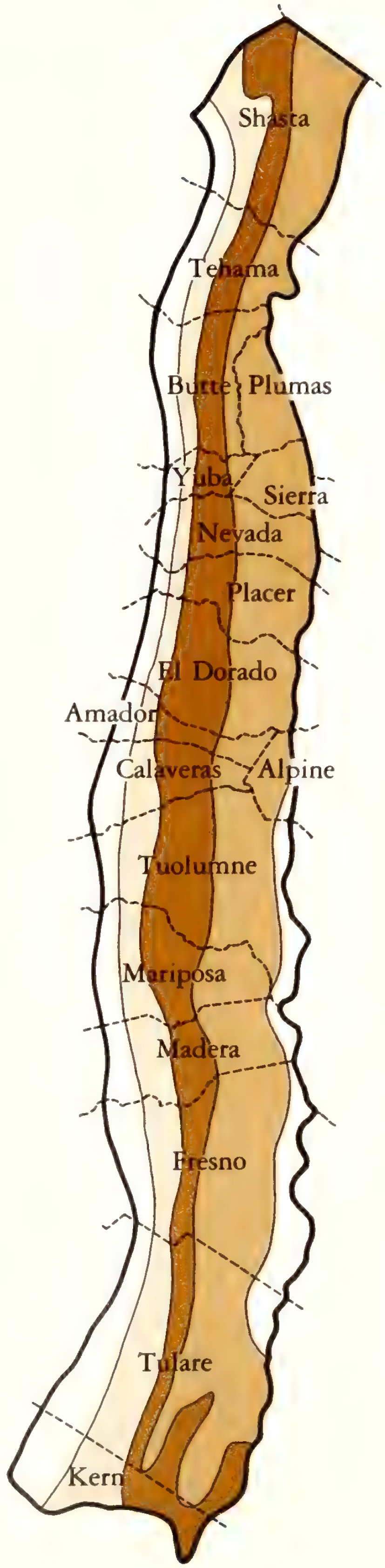
TERRITORY/HOME RANGE: In Idaho, breeding home range size a maximum of 1.0 mi^2 (2.6 km^2) (Ormiston 1966). Breeding territory in same study ranged from 5 to 50 acres (2 to 20 ha).

FOOD HABITS: Eats mainly fruit, acorns, seeds, and green vegetation. Forages on ground and in low shrubs, by scratching, gleaning, grazing, and jumping for leaves and other items.

OTHER:

REFERENCES: Grinnell *et al.* 1918, Ormiston 1966, Johnsgard 1973, Gutierrez 1975.





Chukar

B048 *(Alectoris chukar)*

STATUS: No official listed status. Game species. Uncommon, introduced resident now well established in the southern Sierra Nevada. First released in California in 1932 with several later releases.

DISTRIBUTION/HABITAT: Found in grass/forb stages from annual grasslands through alpine meadows. Prefers open, rocky slopes with 5 to 10 in (6 to 25 cm) of annual precipitation in remote unsettled areas. Moves below level of heavy snows in late fall and winter in coveys of 5 to 40 individuals.

SPECIAL HABITAT REQUIREMENTS: Rock outcrops or talus; water.

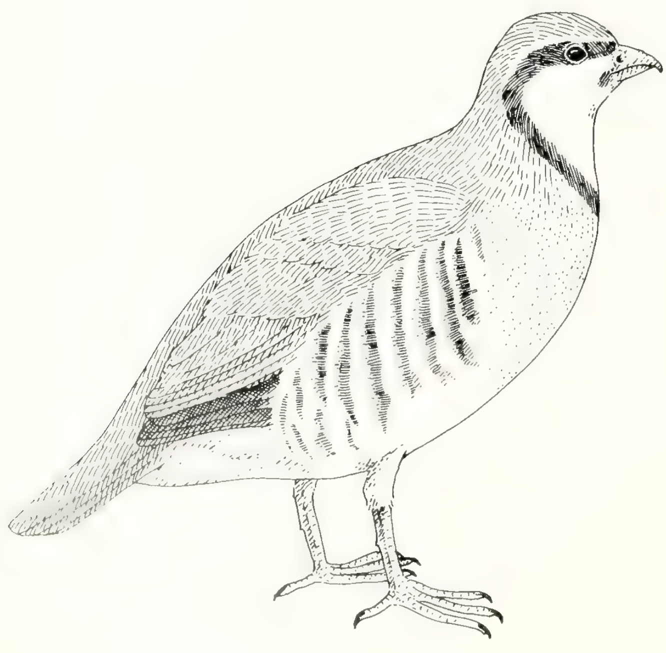
BREEDING: Breeds from early April to early September, with peak from mid-May to early July. Nests in scratched depression in ground, or on rocky slope, usually hidden on three sides by rocks, brush, forbs, or grass, within about 0.5 mi (0.8 km) of water. Clutch size from 10 to 20, with mean of 15. Young likely independent about 3 weeks after leaving nest; leaves nest almost immediately upon hatching.

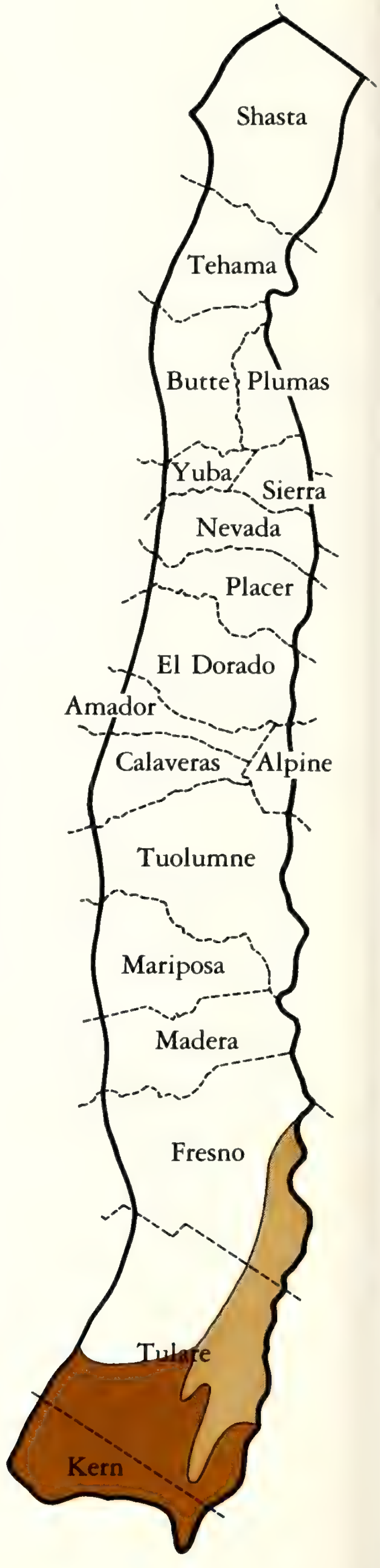
TERRITORY/HOME RANGE: In Utah, birds cruised daily over an area of about 1 mi^2 (2.6 km^2) (Phelps 1955). May also travel 2 to 3 mi (3.2 to 4.8 km) daily to get water during dry periods (Bump 1951, in Johnsgard 1973). Probably nonterritorial (Johnsgard 1973); may defend area around their mate (Mackie and Buechner 1963).

FOOD HABITS: Feeds on grass, forbs, seeds, and some insects, by grazing and gleaning.

OTHER:

REFERENCES: Harper *et al.* 1958, Christensen 1970, Johnsgard 1973.





Turkey

B049 *(Meleagris gallopavo)*

STATUS: No official listed status. Game species. An introduced species, first released in 1908. By 1969, four populations locally well-established on west slope.

DISTRIBUTION/HABITAT: Ranges from digger pine-oak through lodgepole pine. Primarily found in grass/forb and shrub/seedling/sapling stages of ponderosa pine and black oak woodland types. Found in flocks year-round, wanders widely through many habitats, 3 mi (4.8 km) or more per day. In the Sierra Nevada, prefers wooded areas with scattered grassy openings, usually in rugged, hilly terrain. Moves downslope 25 to 50 mi (40 to 80 km) to winter range, determined by food availability and lack of deep snow. Roosts at night in tree near water.

SPECIAL HABITAT REQUIREMENTS: Water; trees/grass-forbs.

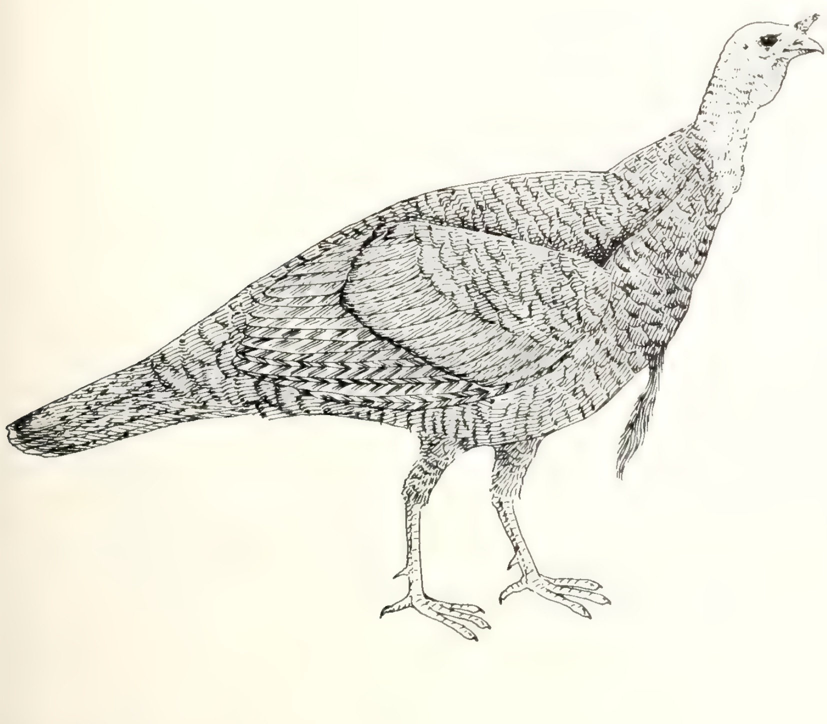
BREEDING: Breeds from late April to mid-August, with peak from early June to late July. Nests in scooped-out depression on dry ground with or without cover and near water. Clutch size from 8 to 15, with 10 most common.

TERRITORY/HOME RANGE: Males apparently defend space on strutting grounds. In Oklahoma, Thomas (1954) reported range from 4 to 8 acres (1.6 to 3.2 ha); in Missouri, Dalke *et al.* (1946) reported range from 100 to 300 acres (40 to 121 ha). Numerous reports of home ranges indicate sizes in winter from about 230 to 1200 acres (93 to 486 ha) and during breeding season from about 160 to 900 acres (65 to 364 ha) (Lewis 1963, Barwick and Speake 1973, and Speake *et al.* 1975).

FOOD HABITS: Eats mainly seeds, acorns, greens, insects, and fruit. Forages on ground, in low vegetation, and sometimes on shrubs and trees by scratching, gleaning or grazing.

OTHER:

REFERENCES: Burger 1954, Schorger 1966, Sanderson and Schultz 1973, Graves 1975, Jackman and Scott 1975.



Virginia Rail

B050 *(Rallus limicola)*

STATUS: No official listed status. Rare visitor in spring, summer, and fall; winter status uncertain. Status generally uncertain because of species' secretive behavior and no systematic distributional study on west slope. Habitat matrix indicates broadest potential occurrence.

DISTRIBUTION/HABITAT: Found in all successional stages from annual grasslands through Jeffrey pine.

SPECIAL HABITAT REQUIREMENTS: Marshes; open water.

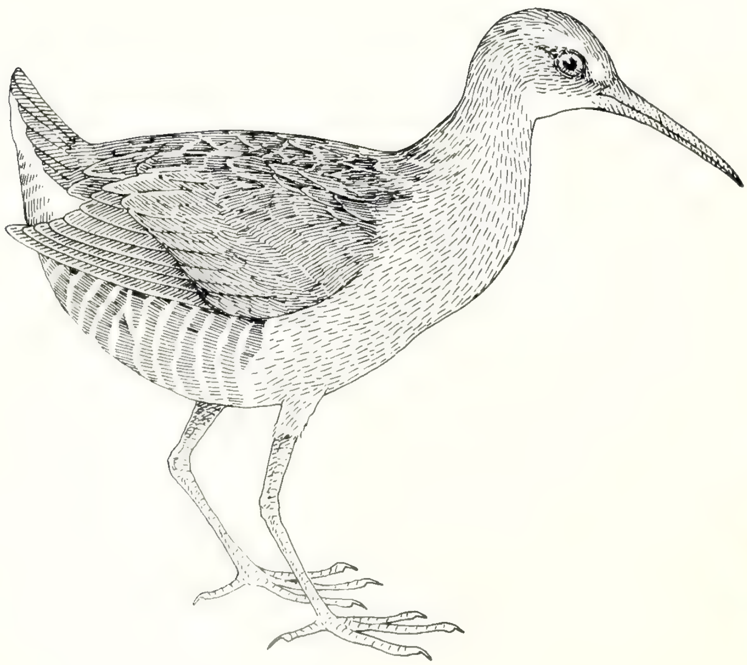
BREEDING: Breeds from early April to early August, with peak from early June to mid-July. Nests built near open water in clumps of dense, emergent vegetation with base of nest touching water. Clutch size from 4 to 13, with 8 or 9 most common. Only two instances of breeding known for west slope.

TERRITORY/HOME RANGE: No data available on size of home range. Territories maintained, no report on sizes (Walkinshaw 1937, Kaufman 1971). Sketch maps in Glahn (1974) suggest territories in Colorado on the order of 5600 to 33,150 ft^2 (520 to 3080 m^2), with mean of about 14,750 ft^2 (1370 m^2) (n = 18).

FOOD HABITS: Eats mainly insects, other invertebrates, seeds, and green vegetation. Forages on ground or floating plant debris amidst dense, emergent vegetation at edge of water, by gleaning.

OTHER:

REFERENCES: Pospichal and Marshall 1954, Horak 1970, Johnsgard 1975a.



American Coot

B051 *(Fulica americana)*

STATUS: No official listed status. Game species. Fairly common spring and fall migrant. Resident breeding species in some localities.

DISTRIBUTION/HABITAT: Found in all successional stages from annual grasslands through Jeffrey pine.

SPECIAL HABITAT REQUIREMENTS: Ponds, lakes, slow-moving streams, or rivers.

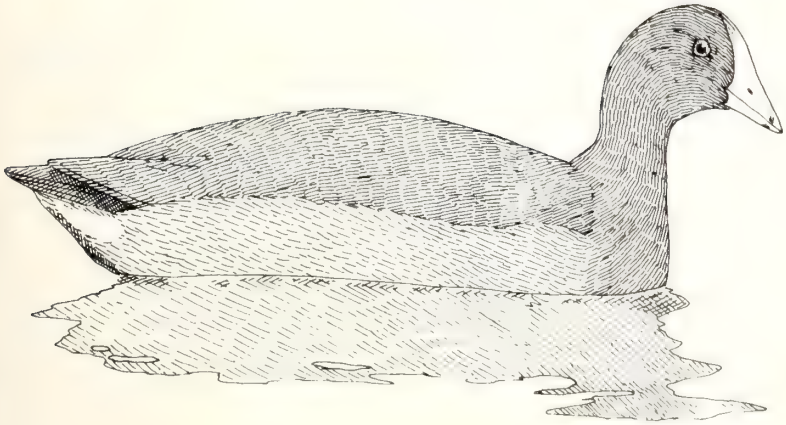
BREEDING: Breeds from early March to late September, with peak from early June to mid-August. Builds several nest-like structures for courtship, display platforms, nests for eggs, and nests for brooding young. Also builds floating nest in emergent vegetation near open water. Clutch size from 4 to 13, with 9 or 10 most common. Few breeding records for west slopes, all from Sequoia-Kings Canyon National Parks.

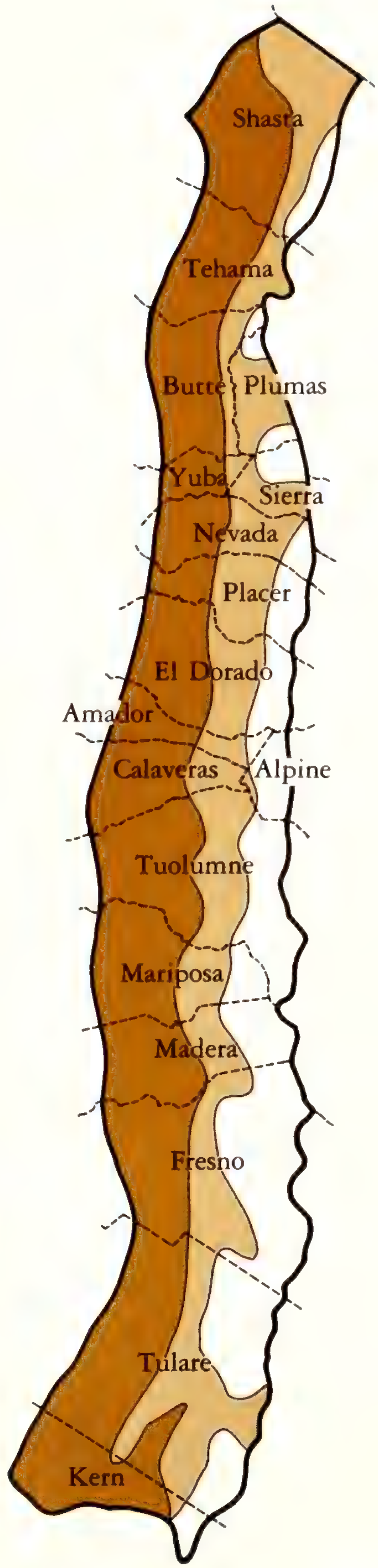
TERRITORY/HOME RANGE: No data available on home range. In Alameda County, size of nine breeding territories ranged from 0.5 to 1.4 acres (0.2 to 0.6 ha), and averaged 1 acre (0.4 ha) (Gullion 1953). Winter territories, held only by resident individuals, ranged from 0.1 to 0.5 acre (0.04 to 0.2 ha) and averaged 0.3 acre (0.1 ha) (n = 10).

FOOD HABITS: Feeds mainly on submerged vegetation, also shoreline vegetation, insects, and aquatic invertebrates. Forages under water or on shoreline by diving and gleaning.

OTHER:

REFERENCES: Gullion 1954; Frederickson 1970, 1977; Johnsgard 1975a.





Killdeer

B052 *(Charadrius vociferus)*

STATUS: No official listed status. Common resident in foothills; uncommon summer visitor to higher elevations. Most widespread and numerous shorebird in the Sierra Nevada.

DISTRIBUTION/HABITAT: Breeds from annual grasslands up to lodgepole pine zone, in open habitats afforded by grasslands, meadows, or early successional stages. Found year-round as high as ponderosa pine and black oak woodland types.

SPECIAL HABITAT REQUIREMENTS: Open terrain; rarely far from ponds, lakes, streams, or rivers.

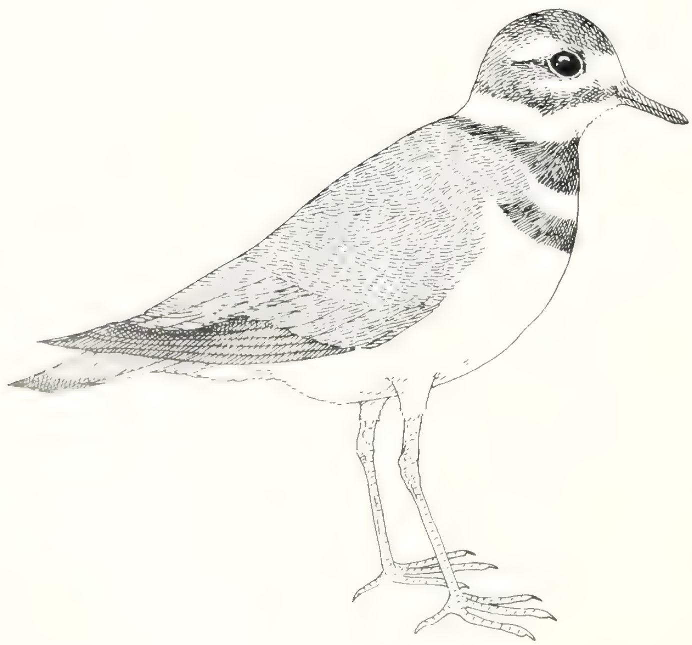
BREEDING: Breeds from early April to early July, with peak from early May to mid-June. Nests on open ground, either gravelly or turfy, near water if possible; found nesting in deserts to alpine meadows. Clutch size from 2 to 4, with 4 most frequent.

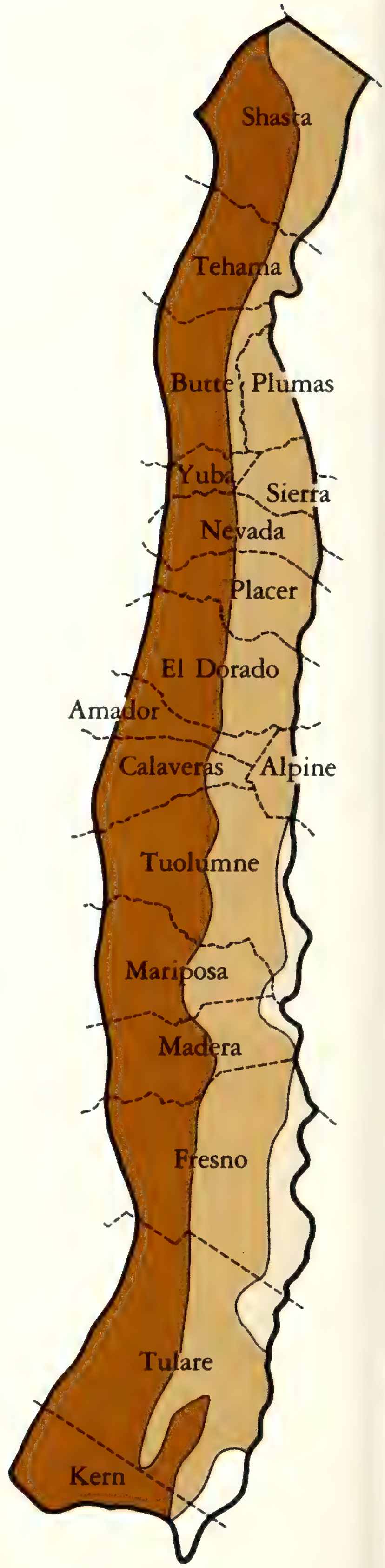
TERRITORY/HOME RANGE: No data available.

FOOD HABITS: Feeds primarily on insects, spiders, snails, earthworms, and vegetable matter on surface of dry or moist ground, or in shallow water.

OTHER:

REFERENCES: Grinnell and Storer 1924, Bent 1929, Stout 1967, Gerstenberg and Jurek 1972, Jurek and Leach 1973.





Common Snipe

B053 *(Capella gallinago)*

STATUS: No official listed status. Game species. Uncommon resident up to 2000 ft (610 m); rare migrant up to 9000 ft (2740 m); rarely nests above 6700 ft (2040 m). Numbers markedly reduced by hunting in early 1900's; some evidence of recovery noted (Grinnell and Miller 1944).

DISTRIBUTION/HABITAT: Breeds from annual grasslands up to mixed-conifer forests; more common at lower elevations. Prefers early seral stages with streams, ponds, springs, or seeps.

SPECIAL HABITAT REQUIREMENTS: Wet margins of ponds, lakes, streams, rivers, or marshes.

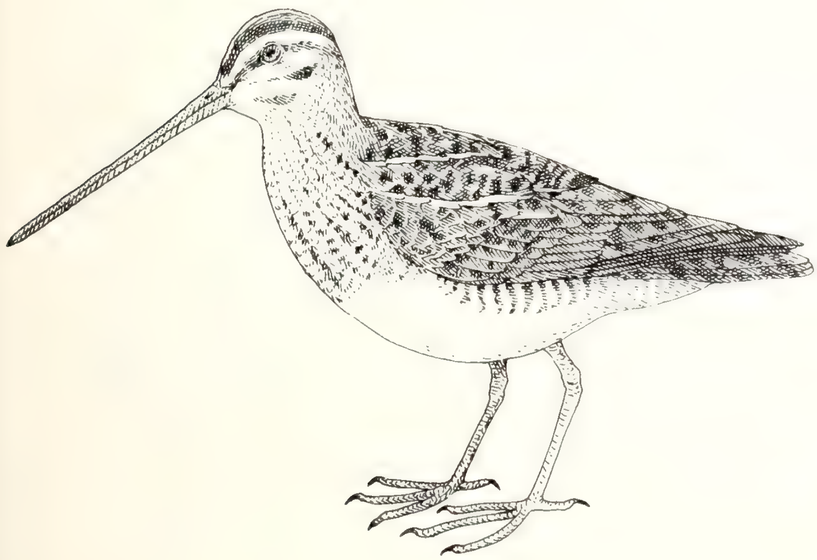
BREEDING: Breeds from late April to early August, with peak from mid-May to late June. Nests on ground in freshwater marshes, grassy borders of slow-moving streams, wet meadows, and farmland. Most clutches contain 4 eggs; some sets of 3 reported.

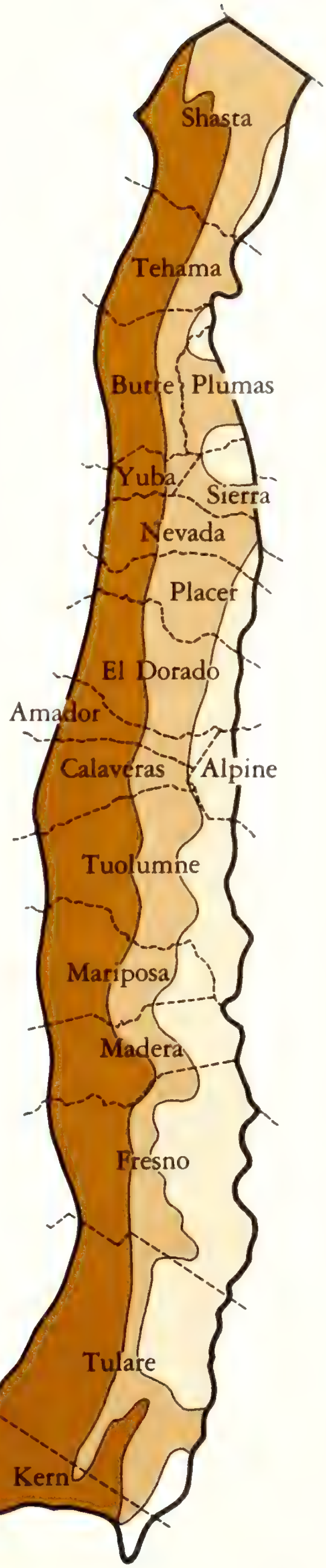
TERRITORY/HOME RANGE: Nesting density ranged from 1.4 to 7.0 pairs per 100 acres (40 ha) (Tuck 1972), and rough sketch maps by Tuck (1972) suggest territory sizes of 5 to 40 acres (2 to 16 ha) before incubation and 1 to 3 acres (0.4 to 1.2 ha) during incubation.

FOOD HABITS: Feeds mostly on insects, earthworms, and crustaceans; also on vegetation. Forages along streamsides and ponds, on shores and in shallows by surface feeding, as well as probing and pecking.

OTHER: Solitary or in pairs during most of year, but in winter somewhat social. Fogarty and Arnold (1977) present management recommendations.

REFERENCES: Bent 1927, Stout 1967, Tuck 1972, Gerstenberg and Jurek 1972, Jurek and Leach 1973.





Spotted Sandpiper

B054 *(Actitis macularia)*

STATUS: No official listed status. Uncommon nesting species from base of mountains to treeline; scarce fall and winter resident at low elevations. More common in northern two-thirds of region and at elevations below 6000 ft (1830 m).

DISTRIBUTION/HABITAT: Primarily found in grass/forb and shrub/seedling/sapling stages from annual grasslands through ponderosa pine and mountain meadows.

SPECIAL HABITAT REQUIREMENTS: Gravelly or sandy margins of ponds, lakes, streams, or rivers.

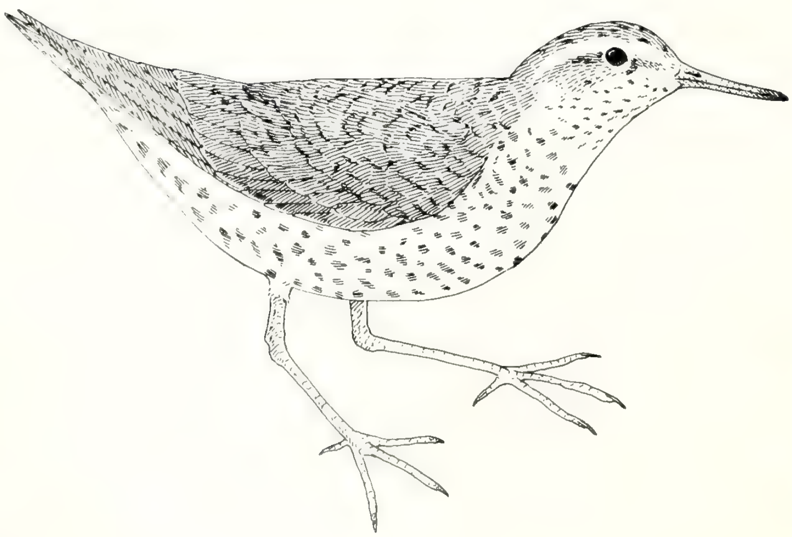
BREEDING: Breeds from early May to early July, with peak from mid-May to late June. Nests usually under thick, low ground cover near water and a display area. Clutch size averages 4.

TERRITORY/HOME RANGE: No data on territory size. Defends breeding territories (Oring and Knudson 1972) and winter territories (Palmer in Stout 1967). In Wyoming, Kuenzel and Weigert (1973) noted species remained in area of about 3 acres (1.2 ha) when food abundant. In Michigan, Nelson (1930) reported broods stayed within about 0.25 mi (0.4 km) of lake shoreline.

FOOD HABITS: Mainly feeds on insects and other invertebrates; also some fish fry. Feeds on margins of sandy, gravelly ponds and streams, meadows, or irrigated fields by snapping at insects, surface feeding.

OTHER:

REFERENCES: Bent 1929, Nelson 1930, Grinnell and Miller 1944, Miller and Miller 1948, Stout 1967, Gerstenberg and Jurek 1972, Jurek and Leach 1973.



American Avocet

B055 *(Recurvirostra americana)*

STATUS: No official listed status. Extremely rare spring and summer visitor to low elevations on west slope; abundant nesting species east of the Sierra Nevada crest (Gaines 1977). Only scattered records exist for west slope above 1000 ft (305 m). Historically more common, but reduction of freshwater marshland by drainage resulted in retraction of breeding range (Grinnell and Miller 1944).

DISTRIBUTION/HABITAT: Found primarily in grass/forb stage of annual grassland through chaparral types, and in mountain meadows.

SPECIAL HABITAT REQUIREMENTS: Open terrain; pond or lake margins.

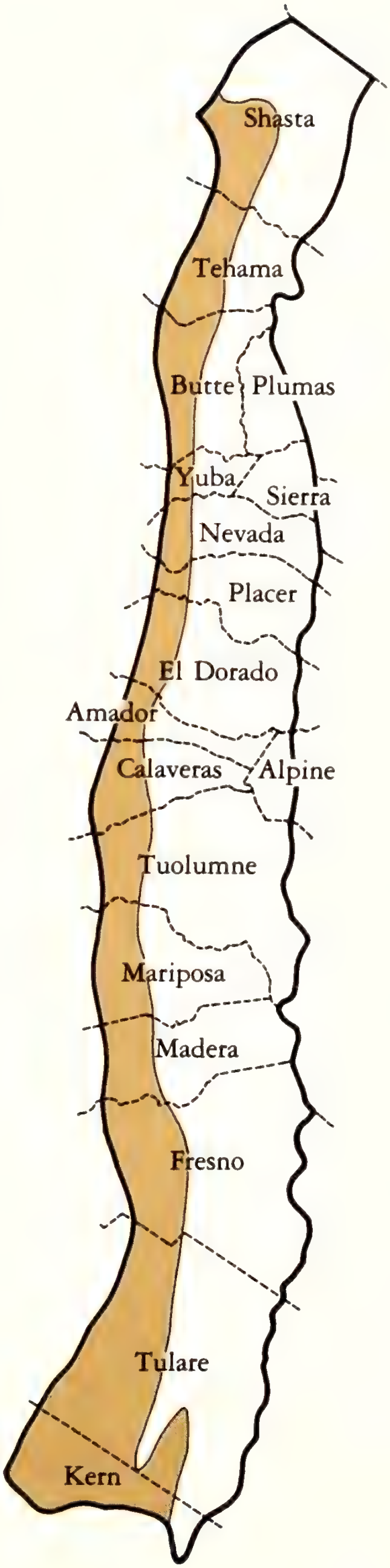
BREEDING: Breeds from mid-April to late June, with peak from early to late May. Nests on dry, sun-baked mudflats or gravelly, sandy islands with scanty vegetation. Clutch size from 3 to 8, with 4 most common.

TERRITORY/HOME RANGE: In Oregon, defended separate territories around nest and feeding areas during breeding season; after young left nest, adults defended area of 65 to 330 ft (20 to 100 m) in diameter around moving brood of chicks (Gibson 1971). In California, defended foraging areas of about 2.5 to 4.9 acres (1 to 2 ha), while nests placed from 6.6 to 138 ft (2 to 42 m) apart along dike; mean separation 72 ft (22 m) (Hamilton 1975).

FOOD HABITS: Eats primarily insects, crustaceans, and rarely small fish; also some seeds. Forages in shallow water over muddy bottom and along pond edges by side-to-side sweeping of bill in shallow water; also by probing and tip-up.

OTHER:

REFERENCES: Bent 1927, Grinnell and Miller 1944, Stout 1967, Gibson 1971, Gerstenberg and Jurek 1972, Jurek and Leach 1973, Hamilton 1975, Gaines 1977.



Wilson's Phalarope

B056 *(Steganopus tricolor)*

STATUS: No official listed status. Extremely rare summer visitor to lakes at all elevations west of the Sierra Nevada crest. Arrives in California by early May, departs for the south by middle of September (Bent 1927).

DISTRIBUTION/HABITAT: Found in grass/forb, shrub/seedling/sapling, and open-canopied pole, medium, and large tree stages from annual grasslands through alpine meadows.

SPECIAL HABITAT REQUIREMENTS: Open terrain; pond, lake, or marsh edges.

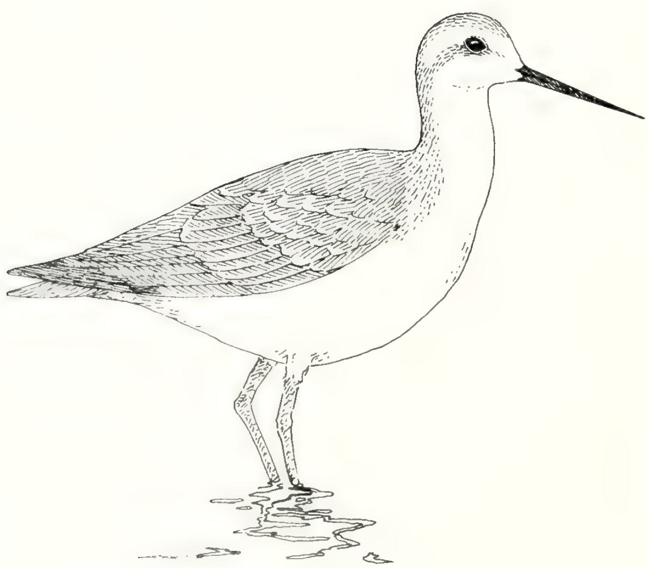
BREEDING: Not known to breed on west slope.

TERRITORY/HOME RANGE: No data available on home range. Not known to be territorial in Alberta (Höhn 1967).

FOOD HABITS: Feeds on insects (adults and larvae), crustaceans, and some marsh plants. Forages on mud flats, dry shore, and open water (shallow or deep) by side-sweeping bill in shallow water, whirling in deep water, gleaning surfaces, and probing in mud.

OTHER:

REFERENCES: Bent 1927, Höhn 1967, Stout 1967, Gerstenberg and Jurek 1972, Jurek and Leach 1973, Gaines 1977.



California Gull

B057 *(Larus californicus)*

STATUS: No official listed status. Uncommon spring and fall migrant and summer visitor.

DISTRIBUTION/HABITAT: Found in all successional stages from annual grasslands through alpine meadows. Most common at higher elevations. Only one winter record on west slope.

SPECIAL HABITAT REQUIREMENTS: Lakes, rivers.

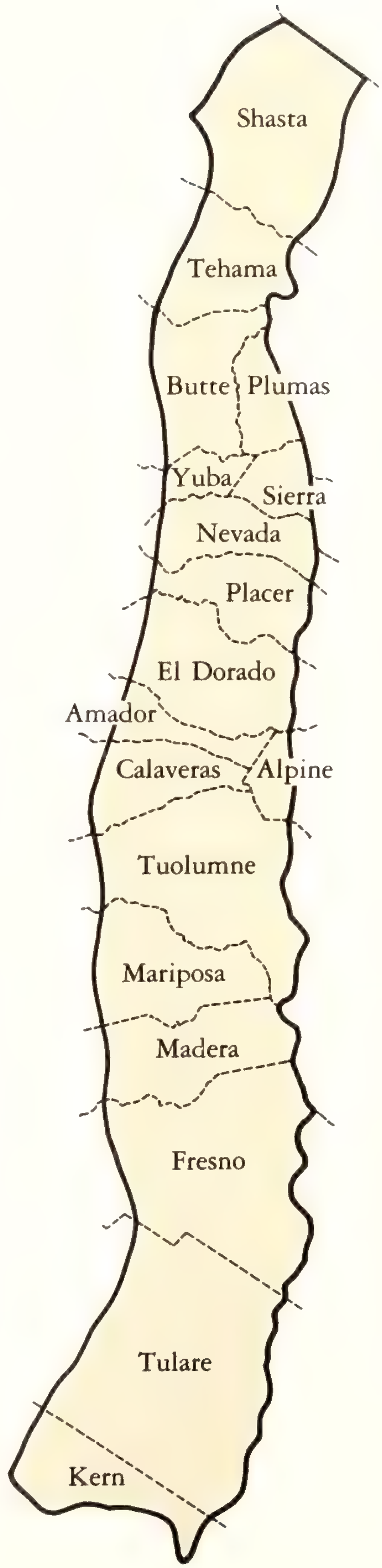
BREEDING: Nonbreeder on west slope of the Sierra Nevada.

TERRITORY/HOME RANGE: Not known to be territorial during nonbreeding period. No data available on home range of nonbreeding birds.

FOOD HABITS: Feeds on garbage, insects, rodents, carrion, plant material, and fish; flies over large area to search ground and water surface; dives for fish.

OTHER:

REFERENCES: Greenhalgh 1952, Behle 1958, Vermeer 1970.



Ring-billed Gull

B058 *(Larus delawarensis)*

STATUS: No official listed status. Rare spring and fall migrant and summer visitor. Status uncertain because easily confused with more common California gull.

DISTRIBUTION/HABITAT: Found in all successional stages from annual grasslands to alpine meadows.

SPECIAL HABITAT REQUIREMENTS: Lakes, rivers.

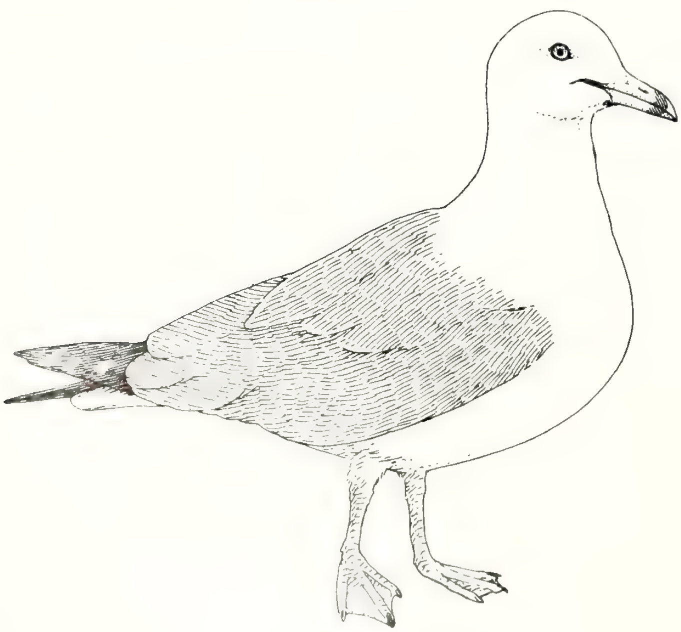
BREEDING: Nonbreeder on west slope of the Sierra Nevada.

TERRITORY/HOME RANGE: Not known to be territorial during nonbreeding period. No data on home range of nonbreeding birds.

FOOD HABITS: Feeds on garbage, plants, insects, rodents, fish, and invertebrates. Forages on ground or near surface of water. Has flight search over large areas and dives for fish.

OTHER:

REFERENCES: Johnston and Forster 1954, Vermeer 1970.



Band-tailed Pigeon

B059 *(Columba fasciata)*

STATUS: No official listed status. Game species. Fairly common resident in oak and conifer belts; also common visitor to higher elevations in the Sierra Nevada. Numbers erratic in winter, depending on food supply.

DISTRIBUTION/HABITAT: Found from blue oak savannah to lodgepole pine types. Found mainly in open-canopied, large tree stages of blue oak savannah, digger pine-oak, ponderosa pine, black oak, mixed-conifer, and deciduous riparian types. Extremely gregarious, even when nesting. After nesting, flocks nomadically search for food. Have traditional mineral springs, roosting areas, and watering spots (Glover 1953b).

SPECIAL HABITAT REQUIREMENTS: Large trees; nearby water.

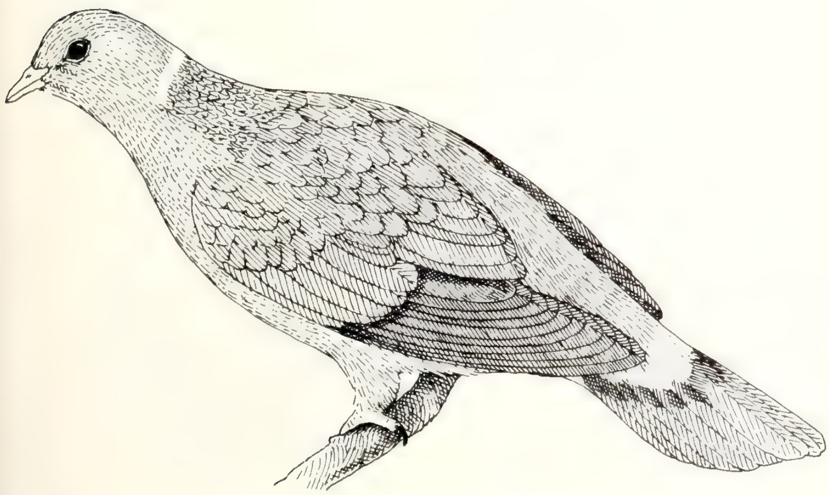
BREEDING: Breeds from early February to mid-October, with peak from early May to mid-July. Will double-brood. Usually nests in areas with dense cover, such as alder thickets or groves of conifers or oaks. Needs sturdy limbs for nest placement and roosting. Proximity to water required. Nest height from 8 to 80 ft (2.4 to 24m), average 20 ft (6.1 m). Clutch size 1 or 2, with 1 most common.

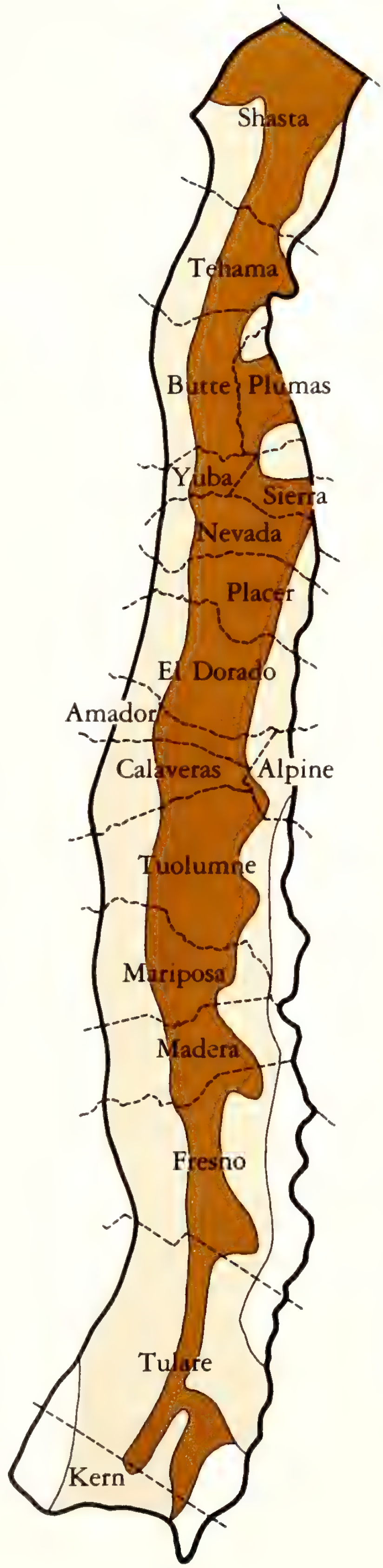
TERRITORY/HOME RANGE: No available data on home range. In Humboldt County, breeding territory roughly estimated to have radius around nest ranging from 0.1 to 0.5 mi (0.2 to 0.8 km), and averaging 0.25 mi (0.4 km) (Glover 1953b). In Contra Costa County, Peeters (1962) estimated that nesting territories ranged from about 2 to 4 acres (0.8 to 1.6 ha). In New Mexico, evidence of colonial nesting reported (Neff 1947).

FOOD HABITS: Main food in winter and spring is mast; berries and grains dominate in summer. Forages in trees and on ground, often in flocks.

OTHER:

REFERENCES: Glover 1953b, Gutierrez *et al.* 1975, Jackman and Scott 1975, Blackman 1976.





Mourning Dove

B060 (*Zenaida macroura*)

STATUS: No official listed status. Game species. Abundant resident in lowlands; extremely rare fall migrant to high elevations.

DISTRIBUTION/HABITAT: Breeds from blue oak savannahs up to Jeffrey pine forests, though breeding above 3000 ft (915 m) rare. Exhibits strong preference for stands with low percent canopy cover.

SPECIAL HABITAT REQUIREMENTS: Trees for nesting; nearby water.

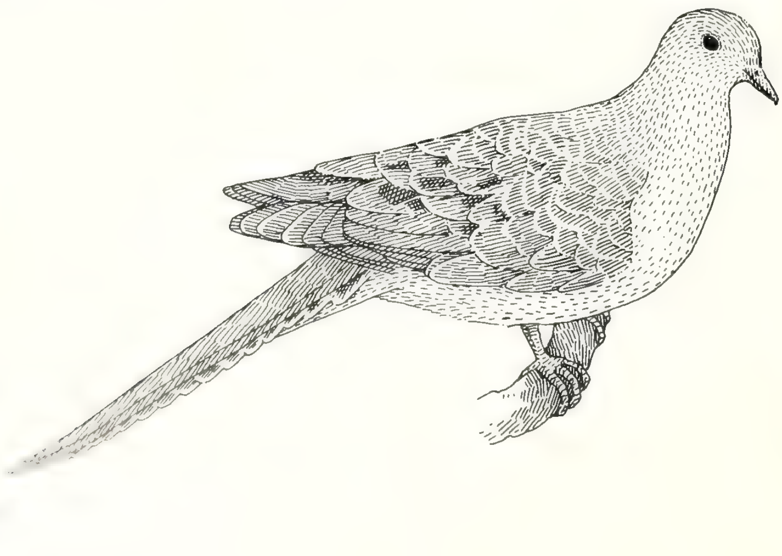
BREEDING: Breeds from mid-March to mid-September, with peak from early may to mid-June. In California, reported nesting almost all year, depending on weather conditions (Nice 1923). Nests in oaks or conifers usually, but also in willows, cottonwoods, and elms. Nest height averages 11 ft (3.4 m). Clutch size almost invariably 2, though clutches of 1 and 3 reported. Multiple brooded (Cowan 1952).

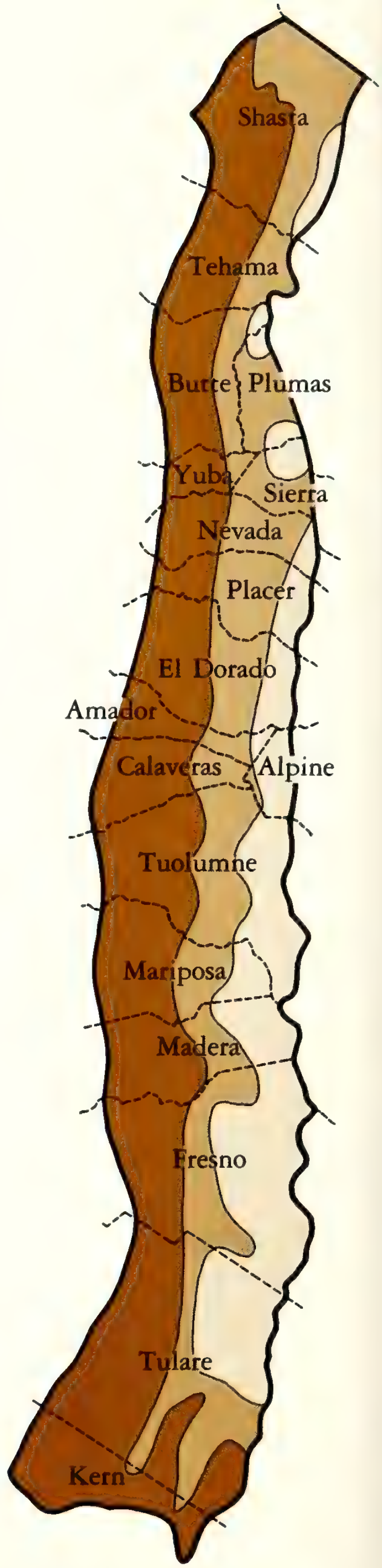
TERRITORY/HOME RANGE: Literature unclear on these aspects of dove biology. Whether or not unmated males defend territories unconfirmed. Mated males defend areas around nest; some observers believe territories decrease in size as nesting season progresses (Lund 1952, Edminster 1954), sometimes to only a few square feet immediately around nest. Records exist of as many as three active nests in same tree (Swank 1955). Others did not observe any marked reduction in territory size (Jackson and Baskett 1964). In Ohio, Mackey (1954) reported an average diameter of nesting territories of 100 ft (30 m). In an urban environment in Missouri, Jackson and Baskett (1964) found a range in size, from 210 to 300 ft (64 to 91 m) in diameter. Doves regularly feed away from their territory. Home range data meagre; Tomlinson *et al.* (1960) reported local summer movements of banded birds in Missouri regularly up to 1 mi (1.6 km) from banding site and as far as 3.25 mi (5.2 km) for one male.

FOOD HABITS: Feeds almost entirely on seeds of grasses, hemp, and cultivated grains, consuming almost no animal matter most of year, although snails important in spring before and during egg laying (S. Harris, pers. commun.). Obtains food from ground by pecking.

OTHER:

REFERENCES: Nice 1922, 1923; Bent 1932; Cowan 1952; Hanson and Kossack 1963.





Roadrunner

B061 *(Geococcyx californianus)*

STATUS: No official listed status. Rare resident in foothills; apparently more common in the past (Sumner and Dixon 1953).

DISTRIBUTION/HABITAT: Confined to chaparral and grass/forb and shrub stages of blue oak and digger pine-oak types, where found year-round.

SPECIAL HABITAT REQUIREMENTS: Nearby water.

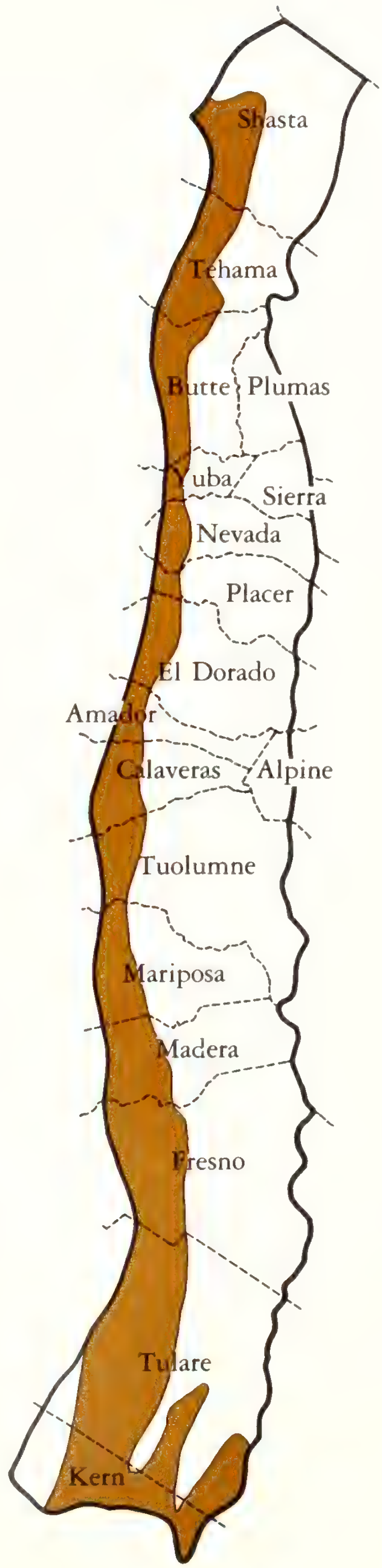
BREEDING: Breeds from late February to late July, with peak from mid-March to early May. Usually nests off ground in trees or shrubs, rarely on ground. Nest height from 0 to 15 ft (0 to 4.6 m) up. Clutch size from 2 to 9, with mean of 5.

TERRITORY/HOME RANGE: Mean home range size of several square miles in California (Bryant 1916), otherwise no data on size of home range or territory.

FOOD HABITS: Eats mainly lizards, insects, spiders, rats, snakes, wild fruit, and seeds. Feeds on ground and in air. Actively pursues prey on ground; sometimes leaps into air to capture food.

OTHER: Reasons for decline in numbers in the western Sierra Nevada unknown; might speculate that recent fire control efforts eliminated much of open habitat that birds require in chaparral or chaparral-like stands of shrubs.

REFERENCES: Bryant 1916, Bent 1940, Ohmart 1973.



Barn Owl

B062 *(Tyto alba)*

STATUS: No official listed status; on the Audubon Society Blue List for 1978. Declining status in many sections of the country not apparent in the western Sierra Nevada. Common resident in appropriate habitat.

DISTRIBUTION/HABITAT: Breeds from annual grasslands upslope into chaparral zone; prefers areas with low percent canopy coverage. Also breeds in mountain meadow areas, generally below 4000 ft (1220 m). In Tulare County, altitudinal vagrants recorded to about 5500 ft (1680 m).

SPECIAL HABITAT REQUIREMENTS: Cliffs, crevices, or old buildings for nesting.

BREEDING: Breeds from late January to early June, with peak in early May; a second breeding period from early June to mid-November peaks in early October. Nests usually on ledges and crannies of old buildings or in crevices in cliffs; rarely uses cavities in oak trees; very rarely digs tunnels in a streambank. Nest height from 20 to 145 ft (6.1 to 44 m), with average of 70 ft (21 m). Clutch size from 3 to 7, with mean of 4.2.

TERRITORY/HOME RANGE: No information on home range. A Utah study indicated area within 15 to 30 ft (4.6 to 9.1 m) of the nest defended (Smith *et al.* 1974).

FOOD HABITS: Eats primarily rodents; insects, reptiles, amphibians, and birds also eaten. Captures prey on ground and in air. A nocturnal hunter; searches and pounces on prey in open areas and occasionally hovers.

OTHER: Increased in range and abundance in California in recent years because of increase in suitable nest sites. Thought to be more common because of reduction in numbers of its predators, such as prairie falcons (Grinnell and Miller 1944).

REFERENCES: Karalus and Eckert 1974, Marti 1974, Smith *et al.* 1974.

Screech Owl

B063 *(Otus asio)*

STATUS: No official listed status. Fairly common resident in suitable habitat.

DISTRIBUTION/HABITAT: Breeds from blue oak savannah up to ponderosa pine and black oak types, as well as in riparian deciduous and lower elevation forest meadows, below 4800 ft (1460 m).

SPECIAL HABITAT REQUIREMENTS: Oaks; nest cavities.

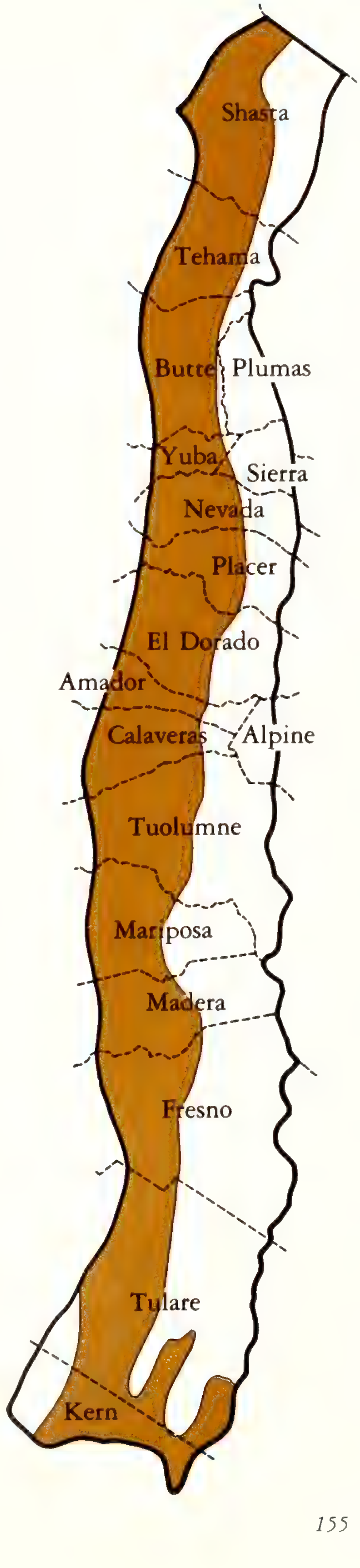
BREEDING: Breeds from early February to early June, with peak from late April to mid-May. Nests in abandoned woodpecker holes or natural cavities in coniferous and deciduous trees. Nest cavities range from 20 to 60 ft (6.1 to 18 m) in height. Clutch size from 2 to 6, with mean of 4.4.

TERRITORY/HOME RANGE: No information available.

FOOD HABITS: In the western Sierra Nevada, eats primarily insects; though rodents, amphibians, reptiles, and small birds also eaten. Captures food on ground, in air, and occasionally from foilage. Searches and pounces on prey during evening and night hours.

OTHER:

REFERENCES: Earhart and Johnson 1970, Karalus and Eckert 1974, Van Camp and Henry 1975.



Flammulated Owl

B064 *(Otus flammeolus)*

STATUS: No official listed status. Common summer resident in suitable habitat; among most migratory of all owls, with most migration thought to be nocturnal.

DISTRIBUTION/HABITAT: Breeds in conifer habitats from ponderosa pine type up to red fir forests. Prefers low to intermediate canopy coverage; particularly common in suitable ponderosa pine forests.

SPECIAL HABITAT REQUIREMENTS: Yellow pines or black oaks (Marcot, pers. commun.) in nesting habitat; nest cavities.

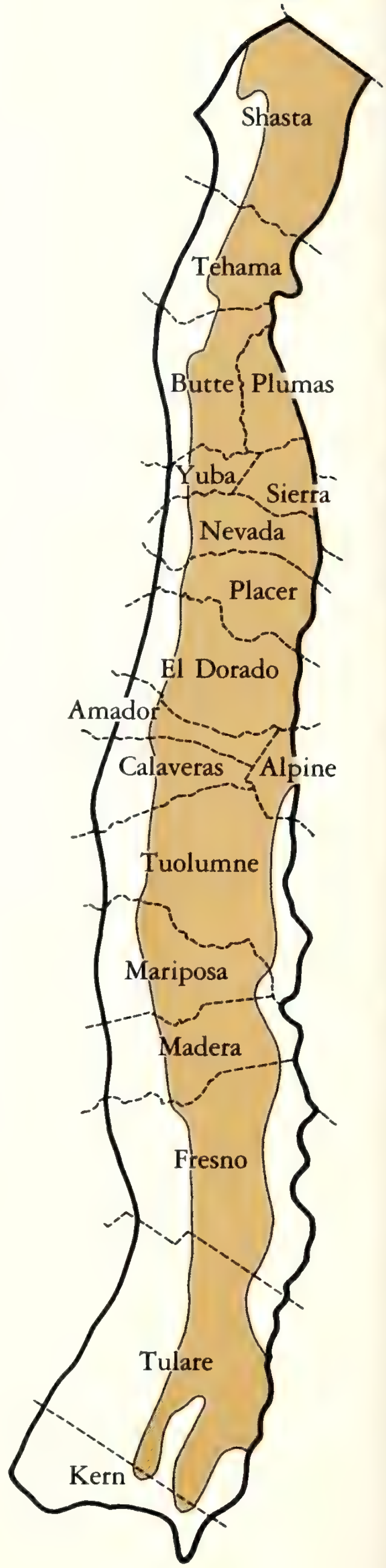
BREEDING: Breeds from late April to early October, with peak from mid-June to mid-July. Nests almost always in flicker nest cavity in aspen, oak, or pine. Nest sites range in height from 7 to 25 ft (2.1 to 7.6 m). Clutch size 2 to 5, with mean of 3.5.

TERRITORY/HOME RANGE: A crude map in a study of territories in Sierra Nevada ponderosa pine forests suggests territories ranging in size from about 7.4 to 15 acres (3 to 6 ha) (Marshall 1939). Data on home range lacking, though Winter (1974) found a density of 2.1 males per 100 acres (40 ha) in the Sierra Nevada.

FOOD HABITS: Feeds primarily on insects, but also some spiders. Takes prey from the air, foliage, or ground. Sometimes searches for and pounces on food; more often hawks for insects from a perch.

OTHER:

REFERENCES: Marshall 1939, Karalus and Eckert 1974, Winter 1974.



Great Horned Owl

B065 *(Bubo virginianus)*

STATUS: No official listed status. Common permanent resident at lower elevations, with some elevational movements seasonally.

DISTRIBUTION/HABITAT: Breeds in all types from blue oak savannah up to mixed conifer; prefers lower elevation sites with low to intermediate canopy coverage. Exhibits considerable upslope movement in summer months for feeding.

SPECIAL HABITAT REQUIREMENTS: Large openings for foraging.

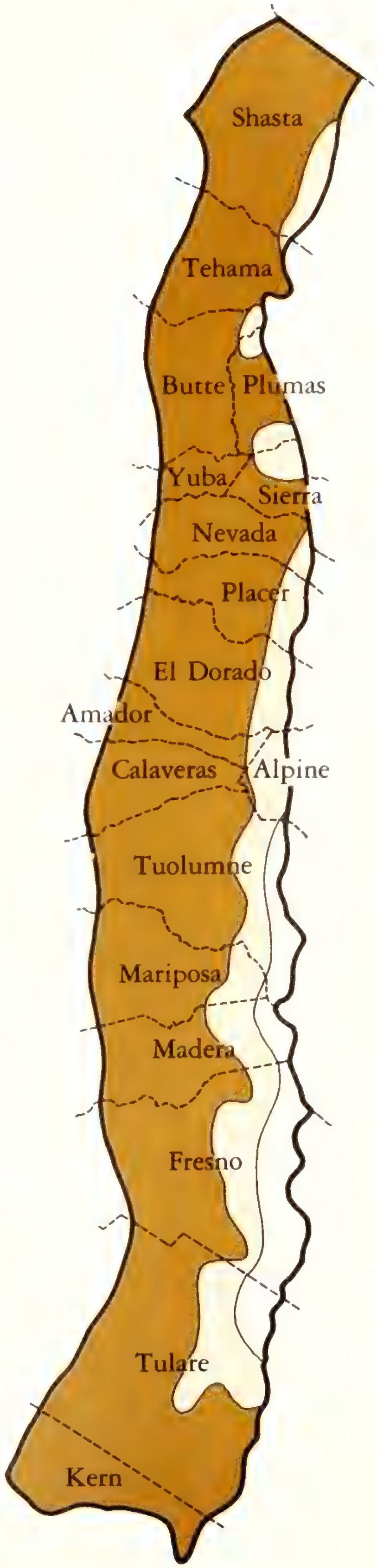
BREEDING: Breeds from mid-January to mid-June, with peak from mid-April to early May. Nests almost always on abandoned nests of red-tailed hawks in tall conifers, hollow logs, cliffs, and other sites. Height of nest ranges from 40 to 70 ft (12 to 21 m). Clutch size from 1 to 5, with mean of 2.

TERRITORY/HOME RANGE: In a Kansas oak woodland, average territory size was 160 acres (65 ha) (Fitch 1958). In heterogeneous habitat at Moose, Wyoming, home range varied from 0.45 to 1.1 mi^2 (1.2 to 2.8 km^2), with mean of 525 acres (212 ha) (Craighead and Craighead 1956).

FOOD HABITS: Small- to medium-sized mammals comprise 90 percent of diet, small birds 5 percent, and insects, amphibians, and reptiles 5 percent. Food captured on the ground, during evening and nighttime hours, by low, rapid flight from perch to ground.

OTHER:

REFERENCES: Craighead and Craighead 1956, Karalus and Eckert 1974, Marti 1974.



Pygmy Owl

B066 *(Glaucidium gnoma)*

STATUS: No official listed status. Fairly common resident; some movement in fall in response to adverse weather.

DISTRIBUTION/HABITAT: Breeds in all timbered types from blue oak savannah up to mixed-conifer forests; prefers sites with low to intermediate canopy coverage. Scarce above 6000 ft (1800 m). Most common near edges of meadows, lakeshores, and other clearings.

SPECIAL HABITAT REQUIREMENTS: Nest cavities.

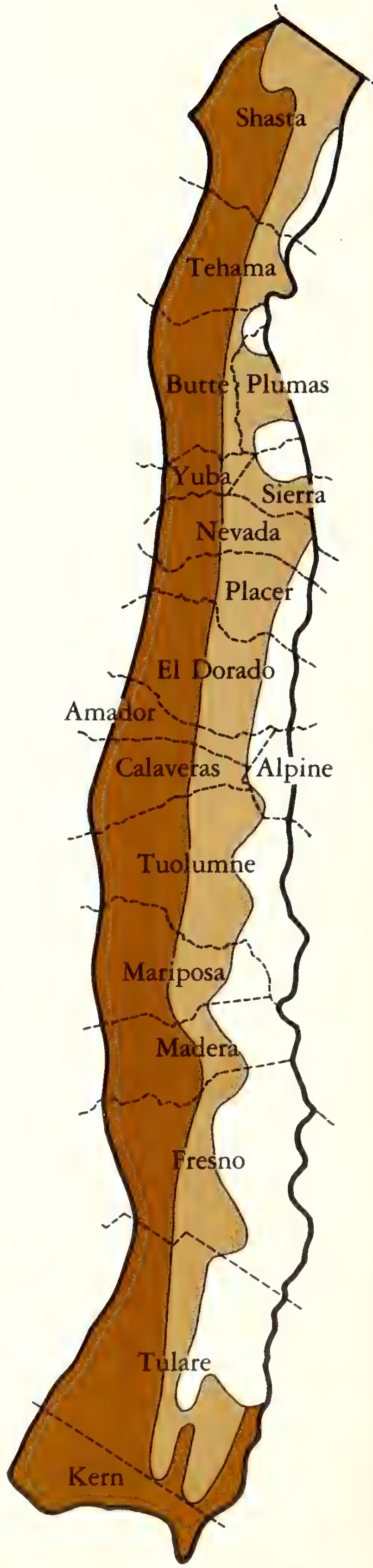
BREEDING: Breeds from early May to late August, with peak from mid-June to mid-July. Almost always nests in abandoned woodpecker hole, from 6 to 75 ft (1.8 to 23 m) up, with average nest height of 40 ft (12 m). Clutch size from 2 to 7, most sets 3 or 4.

TERRITORY/HOME RANGE: No information, though Marshall (1957) refers to "immense territories" and reports following one bird in the same direction for 0.75 mi (1.2 km).

FOOD HABITS: Eats mainly small mammals, small birds, lizards, and insects. Captures prey on ground by search and pounce methods, though some aerial hawking of insects also occurs.

OTHER:

REFERENCES: Earhart and Johnson 1970, Karalus and Eckert 1974.



Burrowing Owl

B067 *(Athene cunicularia)*

STATUS: No official listed status; on the Audubon Society Blue List for 1978. Fairly common resident, considered somewhat reduced in numbers recently because of destruction of ground squirrel colonies.

DISTRIBUTION/HABITAT: Restricted to areas of grasses, forbs, and early shrub stages from annual grasslands up to ponderosa pine type. Breeds in all habitats but prefers lower elevation types. Found as high as 5300 ft (1610 m) in Lassen County.

SPECIAL HABITAT REQUIREMENTS: Ground burrows.

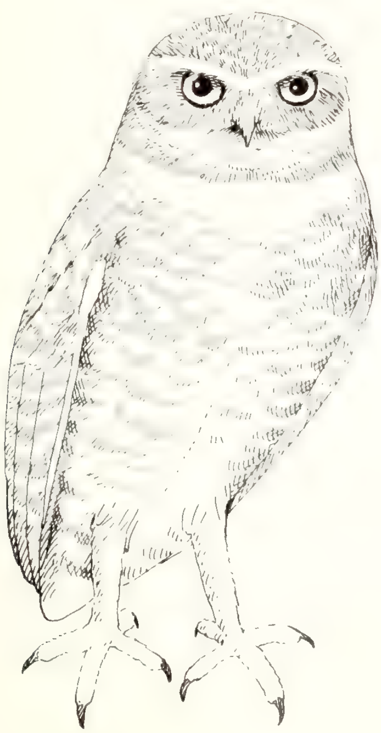
BREEDING: Breeds from early March to late August, with peak from mid-April to mid-May. Nests generally located in bare, level ground in abandoned rodent burrows. Collins and Landry (1977) described a successful method of constructing artificial nesting burrows. Also digs own burrows if necessary. Clutch size from 6 to 11, with mean of 8.

TERRITORY/HOME RANGE: No information on territories, but home ranges at the Oakland Municipal Airport ranged from 0.1 to 4 acres (0.04 to 1.6 ha), averaging 2 acres (0.8 ha) (Thomsen 1971).

FOOD HABITS: Eats mostly insects, but small birds and mammals also eaten. Captures prey in air and on ground. Hunts in the evening and night. Searches and pounces, hover-dives, and also pursues prey on ground by hopping.

OTHER: Probably the most gregarious owl in North America.

REFERENCES: Coulombe 1971, Karalus and Eckert 1974, Zarn 1974.



Spotted Owl

B068 *(Strix occidentalis)*

STATUS: No official listed status. Fairly common permanent resident in suitable habitat, with some seasonal movement downslope and upslope.

DISTRIBUTION/HABITAT: Breeds from ponderosa pine type upslope to lower elevation red fir forests (not above 7600 ft [2300 m]). Mixed conifer the optimum forest type on west slopes of the Sierra Nevada. Black oak in forest canopy enhances habitat suitability (G. Gould, pers. commun.). Stands of large trees, typically with some understory trees combining to give much shade, considered important in breeding sites. Most or all records in pole to medium-sized trees are of young or other nonbreeding birds (N. Johnson, pers. commun.). In Oregon, Forsman *et al.* (1977) reported density about 12 times greater in old-growth forests than in second-growth forests.

SPECIAL HABITAT REQUIREMENTS: Water probably needed; large trees.

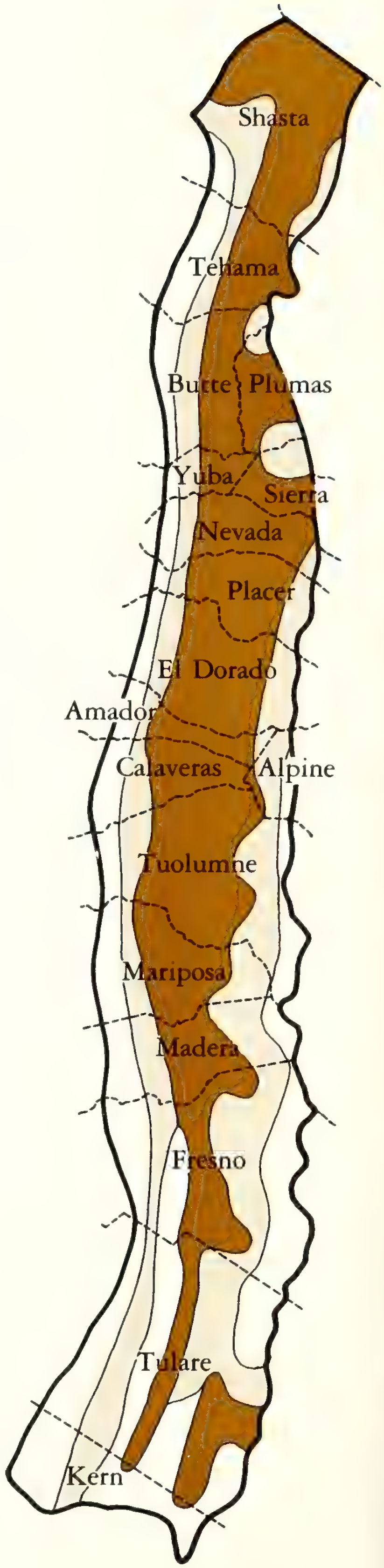
BREEDING: Breeds from early March to late June, with peak from mid-April to mid-June. Nests in tree hollows or occasionally on cliffs and abandoned raptor nests. Nests range in height from 30 to 50 ft (9.1 to 15 m). Clutch size from 1 to 4, with mean of 2.

TERRITORY/HOME RANGE: According to Gould (1974), territory size in conifer forests in the Sierra Nevada ranges from 100 to 340 acres (40 to 138 ha), with mean of 230 acres (93 ha), and home range size varies from 300 to 600 acres (121 to 242 ha), with mean of 450 acres (182 ha). In Oregon, Forsman (pers. commun.) found home ranges from 2270 to 3400 acres (920 to 1375 ha), with mean of 2910 acres (1177 ha), on the basis of 8 birds with radio transmitters. Adjacent birds overlapped 3 to 25 percent (mean 12 percent) in home ranges; members of pairs overlapped about 66 percent.

FOOD HABITS: Eats primarily small mammals, large insects, and small birds. Captures most of prey by search and pounce methods in forest canopy. Fully nocturnal.

OTHER: Until recently, considered rare throughout range. A study by Gould (1974), however, revealed fairly common in dense, coniferous forests at mid-elevations. Because of their solitary, nocturnal habits, rarely seen.

REFERENCES: Marshall 1942, Gould 1974, Jackman and Scott 1975, Forsman *et al.* 1977.



Great Gray Owl

B069 *(Strix nebulosa)*

STATUS: No official listed status, though probably rarest of all owls in the western Sierra Nevada. A rare and localized resident; exhibits some upslope movement in late summer and fall.

DISTRIBUTION/HABITAT: Breeds in mixed-conifer and red fir forests; prefers dense stands bordering meadows. Found in lodgepole pine forests in late summer and fall and in ponderosa pine forests in fall and winter.
Note: Range map shows breeding and nonbreeding distributions over considerable extent of the western Sierra Nevada, although no confirmed record of breeding outside Yosemite National Park. Ranges given based on occurrence of suitable habitat, where presence seems likely.

SPECIAL HABITAT REQUIREMENTS: Trees/grass-forbs.

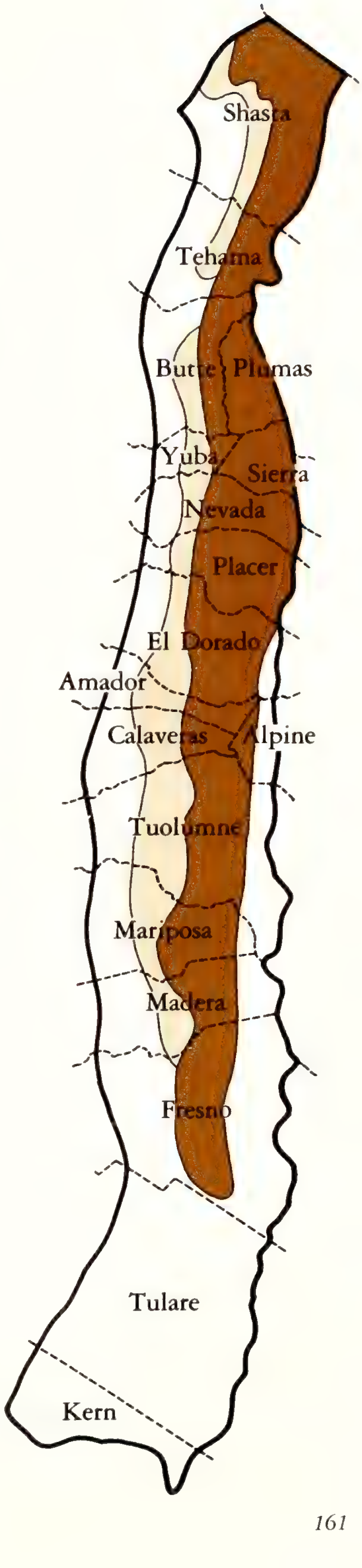
BREEDING: Breeds from late Feburary to mid-June, with peak from mid-April to late May. Nests in abandoned goshawk or red-tailed hawk nest in dense conifer or deciduous tree, or on top of large broken snag, from 50 to 100 ft (15 to 30 m) above ground. Clutch size 1 to 5, with mean of 3.

TERRITORY/HOME RANGE: In Quebec, Brenton and Pittaway (1971) reported mean territory size of 112 acres (45 ha) in coniferous forest. In Wyoming, Craighead and Craighead (1956) reported variation in home range size from 640 to 1000 acres (259 to 405 ha) in coniferous forests.

FOOD HABITS: Eats primarily medium-sized mammals and some birds (to grouse size). Captures prey most often in meadows, on the ground, but occasionally in shrubs. Searches and pounces, and sometimes hovers, in capturing prey.

OTHER: May be more common than number of records indicate. Should be sought in the central and northern Sierra Nevada in suitable habitat.

REFERENCES: Brenton and Pittaway 1971, Karalus and Eckert 1974, Jackman and Scott 1975.



Long-eared Owl

B070 *(Asio otus)*

STATUS: No official listed status. Fairly common resident in riparian habitats; some westward movement in fall.

DISTRIBUTION/HABITAT: Breeds in lower elevation habitats from blue oak savannah up to ponderosa pine and black oak types. Occurrence in these types depends on presence of nearby riparian habitat.

SPECIAL HABITAT REQUIREMENTS: Trees/grass-forbs; riparian habitat nearby.

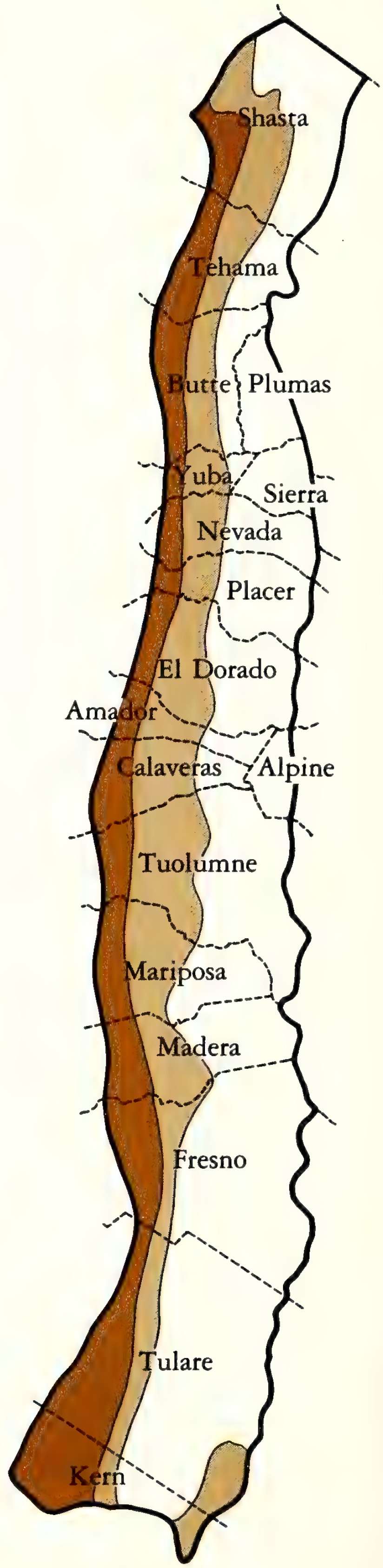
BREEDING: Breeds from early March to late June, with peak from early April to late May. Nests in dense foliage, almost invariably in abandoned nest of magpie, crow, hawk, or heron. Nests from 15 to 50 ft (4.6 to 15 m) above ground, usually between 20 to 30 ft (6.1 to 9.1 m) up. Three to 9 eggs per clutch, with mean of 5.

TERRITORY/HOME RANGE: No information available on territory. Near Moose, Wyoming, Craighead and Craighead (1956) reported home ranges from 0.13 to 0.41 m^2 (0.34 to 1.06 km^2), with average of 136 acres (55 ha), in riparian habitat.

FOOD HABITS: Eats mainly rodents but also preys on birds, including screech owls. Captures food on ground and occasionally in thickets and shrubs in riparian woodland. Searches for and pounces on prey, forages in evening and nighttime hours.

OTHER: Recent decline in numbers because of extensive destruction of riparian habitat and groves of live oaks. Has become highly localized in the Sierra Nevada.

REFERENCES: Randal and Austing 1952, Karalus and Eckert 1974, Marti 1974.



Short-eared Owl

B071 *(Asio flammeus)*

STATUS: No official listed status; on the Audubon Society Blue List for 1978. Small resident population in the western Sierra Nevada; in winter, a large migrant population moves into low elevation grasslands.

DISTRIBUTION/HABITAT: Nests in annual grasslands below about 2000 ft (610 m). During nonbreeding period, may be found in blue oak savannah, digger pine/oak woodlands, and early seral stages of chaparral. Prefers sites with few or no trees.

SPECIAL HABITAT REQUIREMENTS: Annual grassland or marsh.

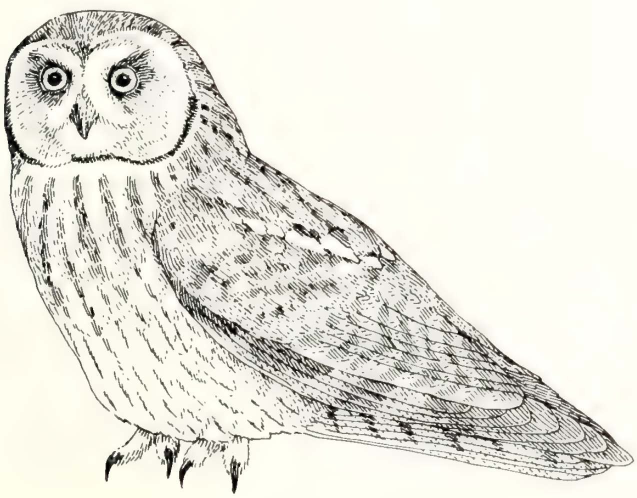
BREEDING: Breeds from late March to early July, with peak from late April to late May. Nests on ground, in a slight depression, or rarely in underground burrows. Clutch size 4 to 14, with 5 to 7 most frequent.

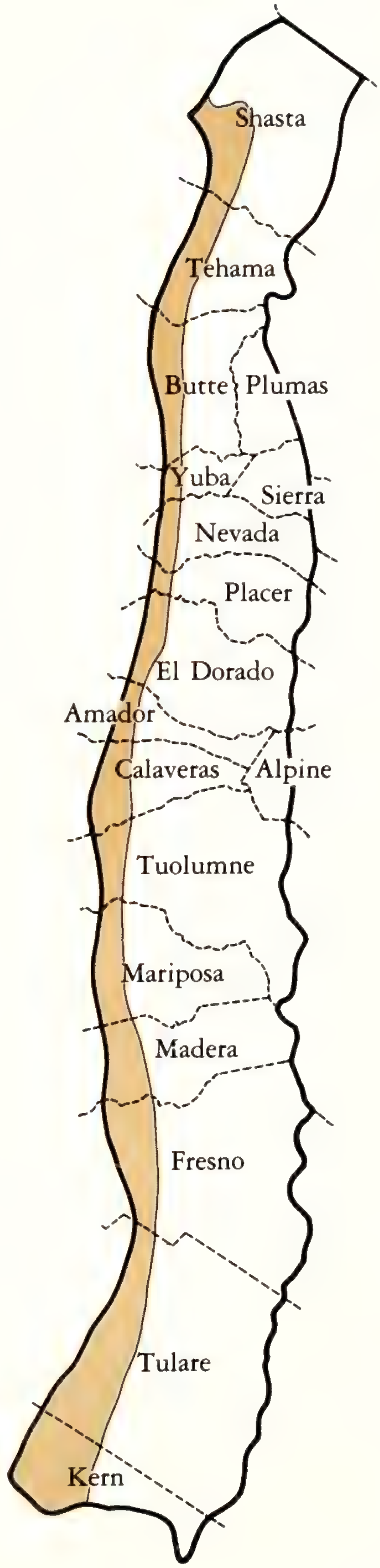
TERRITORY/HOME RANGE: In Manitoba's marsh-prairie, breeding territories in 1969 averaged 183 acres (74 ha), with range from 57 to 242 acres (23 to 98 ha) (n= 5); a single territory in 1968 occupied 300 acres (121 ha) (Clark 1975). In Alaska, Pitelka *et al.* (1955) reported breeding territories of "about 50 acres" (20 ha). In European populations, reports of annual variations in mean territory size range from 44 to 339 acres (18 to 137 ha) (Lockie 1955). Extreme differences in mean territory size related to prey density: denser prey apparently attracted more owls, so territories decreased in size. No data available on home range.

FOOD HABITS: Eats voles, reptiles, and (rarely) amphibians; takes song-birds during nesting season. Captures prey on ground. Searches and pounces over meadows and marshes during daylight and evening hours.

OTHER: Most suitable habitat in the Sierra Nevada destroyed by grazing by sheep, water diversion, and recreational development. Habitat in Central Valley reduced significantly by cultivation and marsh drainage. Although largely restricted to low elevations, altitudinal vargrants seen up to 11,000 ft (3350 m) in Yosemite National Park.

REFERENCES: Karalus and Eckert 1974, Clark 1975, Murray 1976.





Saw-whet Owl

B072 *(Aegolius acadicus)*

STATUS: No official listed status. Poorly known species; considered resident in suitable habitat; possibly some altitudinal movement in response to adverse weather conditions.

DISTRIBUTION/HABITAT: Breeds in mid-elevation habitats from digger pine-oak type up to the red fir zone. Prefers stands of intermediate canopy coverage.

SPECIAL HABITAT REQUIREMENTS: Trees/grass-forbs; nest cavities.

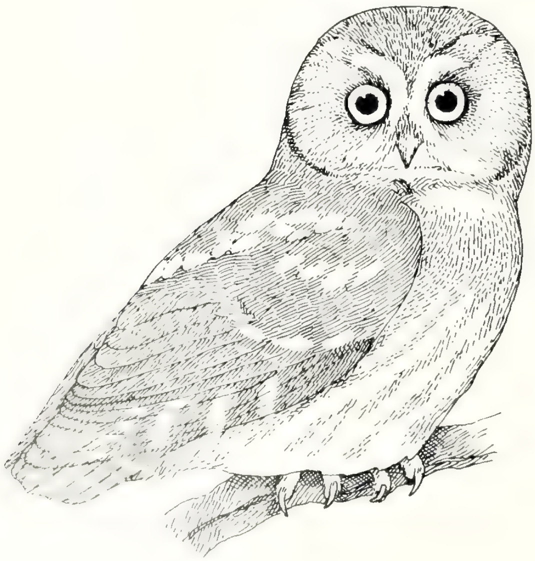
BREEDING: Breeds from early March to late August, with peak from mid-May to mid-June. Nests usually in abandoned flicker nest cavity, from 5 to 25 ft (1.5 to 7.6 m) up. Clutch size from 3 to 7, with mean of 5.

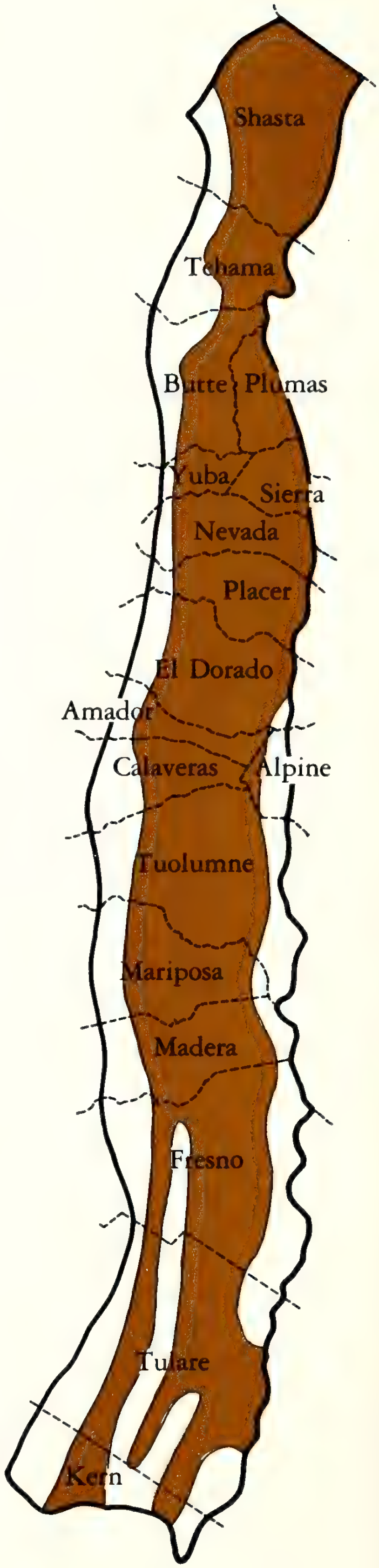
TERRITORY/HOME RANGE: In a cedar swamp in Minnesota, Forbes and Warner (1947) found home range size of a single, radio-tagged bird in winter was 281 acres (114 ha); 76 acres (31 ha) of that seldom used. Bird's movements tracked for 20-day period.

FOOD HABITS: Eats small mammals and birds, reptiles, amphibians, and large insects. Captures prey usually on ground, rarely in air. Searches and pounces, typically at night, but sometimes in evening. Also does some aerial flycatching.

OTHER: Records geographically and chronologically scattered; therefore, difficult to generalize about distribution and abundance. A tame owl, allowing close approach, rarely flushed by observer, and usually overlooked.

REFERENCES: Mumford and Zusi 1958, Forbes and Warner 1974, Karalus and Eckert 1974.





Poor-will

B073 *(Phalaenoptilus nuttallii)*

STATUS: No official listed status. Fairly common summer visitor to low and middle elevations; rare at higher elevations in late summer and early fall.

DISTRIBUTION/HABITAT: Breeds from digger pine-oak woodlands up to Jeffrey pine forests, especially in open habitats as represented by early seral stages.

SPECIAL HABITAT REQUIREMENTS: Trees/shrubs; rock outcrops or logs for nesting cover.

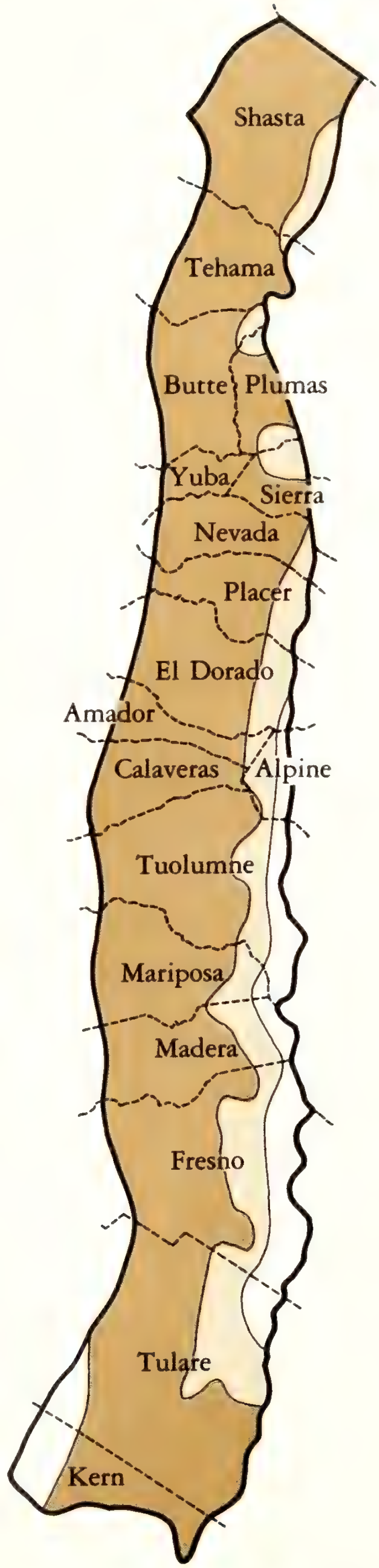
BREEDING: Breeds from mid-March to early August, with peak from early May to late June. Nests on ground, usually in scrape matted with pine needles, typically next to a log and concealed by shrubs or rock outcropping. Requires clear, wide-angle view from nest. Typically, 2 eggs per clutch.

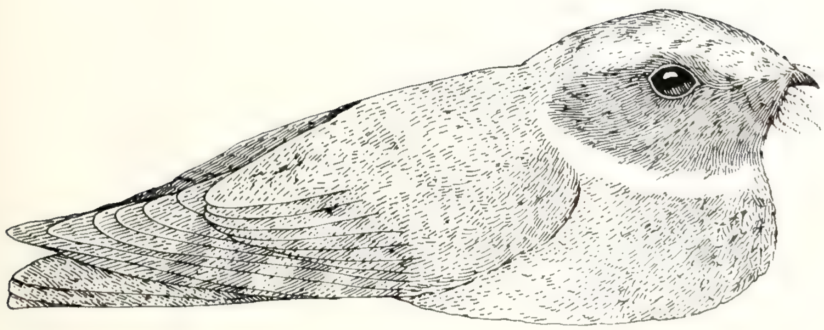
TERRITORY/HOME RANGE: No information available.

FOOD HABITS: Insects make up entire diet; captures mostly in air by making short, vertical, hawking flights from ground. Captures some insects on ground.

OTHER: Nocturnal; sometimes enters state of torpor.

REFERENCES: Aldrich 1935, Bent 1940, Grinnell and Miller 1944.





Common Nighthawk

B074 *(Chordeiles minor)*

STATUS: No official listed status. Uncommon spring migrant and summer visitor to middle and high elevations.

DISTRIBUTION/HABITAT: Breeds from chaparral zone up to lodgepole pine forests; prefers open sites, as in early seral stages. Rare nesting records to as high as 11,000 ft (3350 m).

SPECIAL HABITAT REQUIREMENTS: Open terrain for feeding.

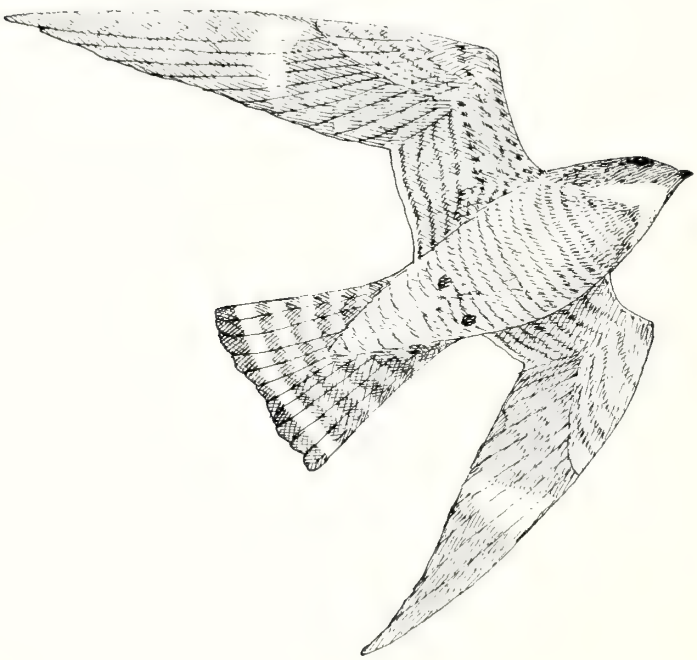
BREEDING: Breeds from mid-March to late July, with peak from mid-June to late July. Nests on ground in open, gravelly or sandy areas unobstructed by tall shrubs or trees, as in forest burns, agricultural fields, creekbeds, or gravelled rooftops. Clutch typically contains 2 eggs.

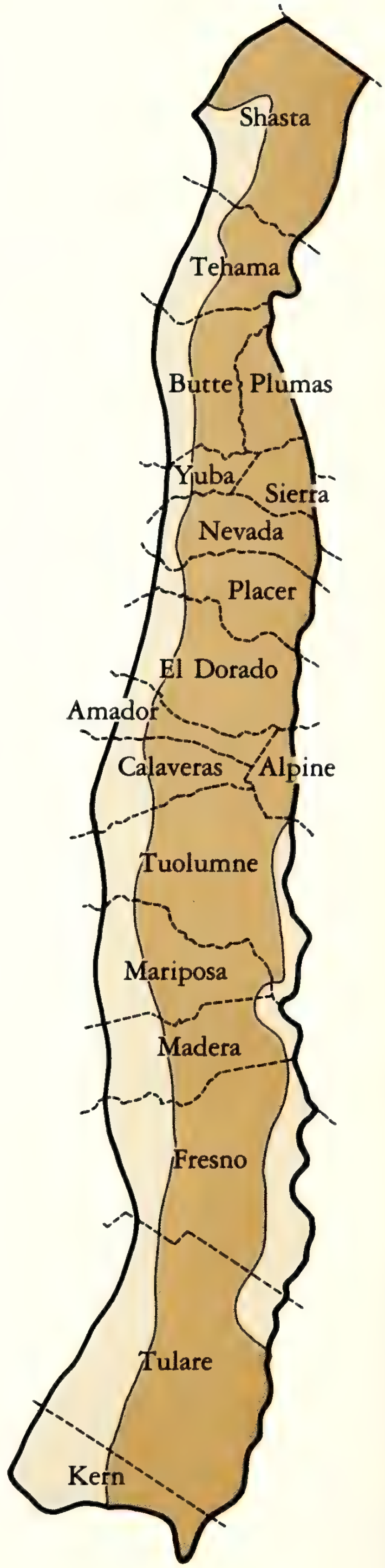
TERRITORY/HOME RANGE: In Kansas, Fitch (1958) reported a home range at least 0.5 mi (0.8 km) in diameter. In Michigan, mean territory size reported by Armstrong (1965) as 26 acres (10.5 ha), with range from 10.3 to 57 acres (4.2 to 23.1 ha).

FOOD HABITS: Feeds primarily on flying insects captured by swooping through swarms of insects with mouth open wide. Some vegetable matter eaten. Forages low over ground, generally beginning at dusk and continuing into dark. Most foraging done over the territory.

OTHER:

REFERENCES: Grinnell and Miller 1944, Selander 1954, Caccamise 1974.





Black Swift

B075 *(Cypseloides niger)*

STATUS: No official listed status. Uncommon summer resident and spring migrant.

DISTRIBUTION/HABITAT: Breeds from ponderosa pine and black oak woodland types up to Jeffrey pine forest. Successional stage unimportant, providing moist cliff faces available. In spring and summer, forages over lowlands at least as far downslope as blue oak savannahs.

SPECIAL HABITAT REQUIREMENTS: Cliffs for nesting.

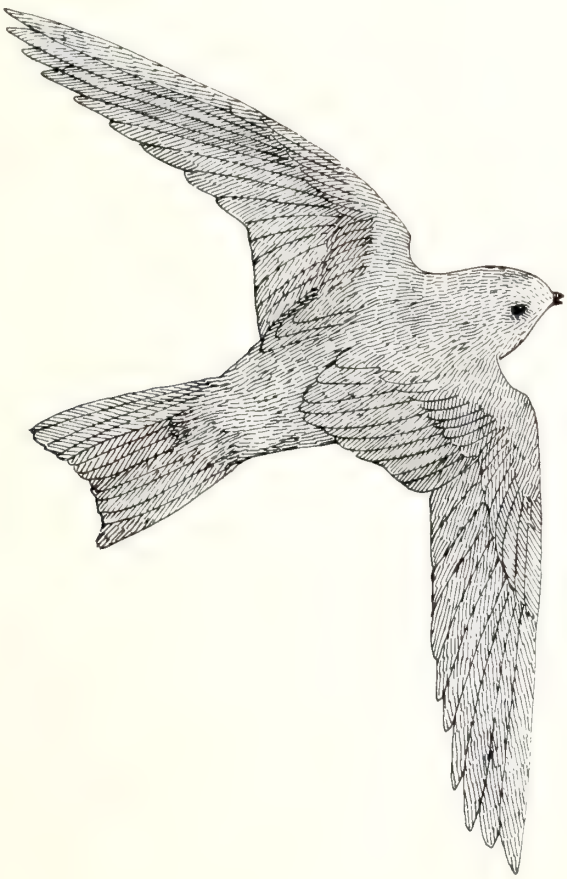
BREEDING: Breeds from early June to late August, with peak from late June to early August. Nests in crevice on sheer, high, moist cliff, often behind waterfall, or hit by spray. Clutch always contains only 1 egg. Nests in small, widely scattered colonies of about 5 to 15 pairs.

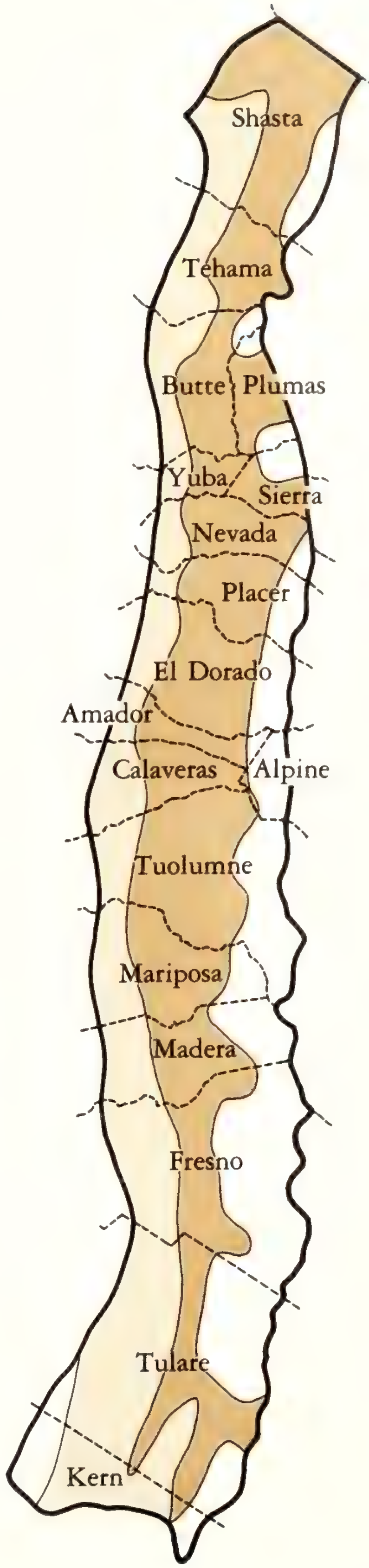
TERRITORY/HOME RANGE: Home range large (Grinnell and Miller 1944), though precise data on size lacking. No data on territory size; territory confined to area immediately surrounding nest site.

FOOD HABITS: Feeds exclusively on flying insects captured usually high in air during sustained, long-distance foraging flights over all types of terrain.

OTHER:

REFERENCES: Bent 1940, Knorr 1961, Hunter and Baldwin 1962.





Vaux's Swift

B076 *(Chaetura vauxi)*

STATUS: No official listed status. Uncommon migrant and summer resident; only one confirmed breeding record for the Sierra Nevada, but probably breeds regularly in small numbers.

DISTRIBUTION/HABITAT: Breeds in areas with large trees in ponderosa pine, mixed-conifer, and Jeffrey pine forests, and possibly in black oak woodlands. Forages regularly downslope to digger pine-oak woodlands.

SPECIAL HABITAT REQUIREMENTS: Hollow stubs or snags for nesting.

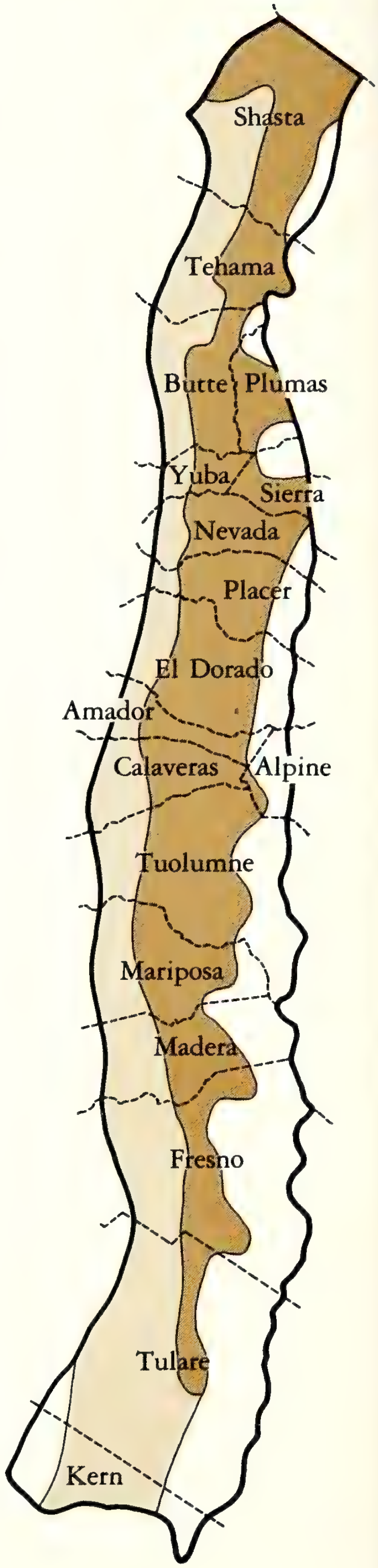
BREEDING: Breeds from early May to early August, with peak from mid-June to late July. Nests usually in tall, hollow, dead stub, frequently one burned out. Nests usually within 1.6 ft (0.5 m) of bottom of cavity and attached to vertical surface. Nest height ranges from below ground level to at least 40 ft (12 m). Clutch size from 3 to 7, with mean of about 5.

TERRITORY/HOME RANGE: No data on either, though likely the only defended area would be immediate vicinity of nest.

FOOD HABITS: Feeds exclusively on flying insects captured in mid-air in forest openings, especially over lakeshores and streams. Forages in extended, continuous flights, cruising back and forth through swarms of insects.

OTHER: Forest fires may be crucial source of suitable nest sites.

REFERENCES: Bent 1940, Baldwin and Hunter 1963, Baldwin and Zaczkowski 1963.



White-throated Swift

B077 *(Aeronautes saxatalis)*

STATUS: No official listed status. Abundant spring migrant and summer resident, expecially from Yosemite National Park southward.

DISTRIBUTION/HABITAT: Breeds from annual grasslands on up through all habitat types to as high as Jeffrey pine zone, and regularly forages up to lodgepole pine forests.

SPECIAL HABITAT REQUIREMENTS: Cliffs for nesting.

BREEDING: Breeds from early May to mid-August, with peak from late May to late July. Nests in deep crevice in steep, rocky cliff face, from 10 to 200 ft (3.1 to 61 m) or more above base of cliff. Clutch contains from 3 to 6 eggs, with mode of 4.

TERRITORY/HOME RANGE: No data on territory. Home range extremely large (Grinnell and Miller 1944).

FOOD HABITS: Eats flying insects captured over any terrain by flying swiftly back and forth through swarms of insects, usually high above ground.

OTHER:

REFERENCES: Bent 1940, Grinnell and Miller 1944, Bartholomew *et al.* 1957.

Black-chinned Hummingbird

B078 *(Archilochus alexandri)*

STATUS: No official listed status. Fairly common spring and summer visitor to low and middle elevations; rare at high elevations after breeding season (T. Manolis, pers. commun.).

DISTRIBUTION/HABITAT: Breeds in blue oak savannahs, digger pine-oak woodlands, and low elevation riparian deciduous habitats; prefers sites with low percentage canopy coverage. Some upslope movement in late summer to as high as the red fir zone.

SPECIAL HABITAT REQUIREMENTS: Nectar source; water.

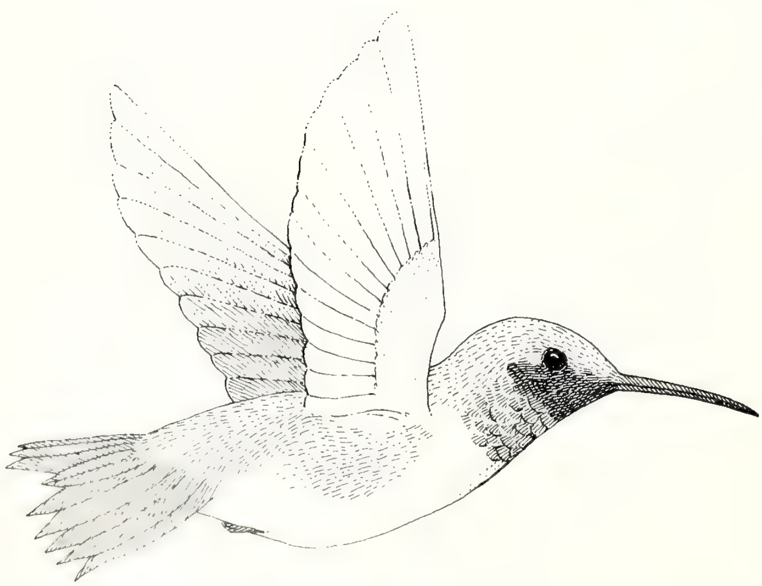
BREEDING: Breeds from early April to late July, with peak from mid-May to late July. Nests in foliage of small trees or shrubs near creeks or springs; prefers live oaks. Nest height from 3 to 30 ft (0.9 to 9.1 m). Typically 2 eggs per clutch.

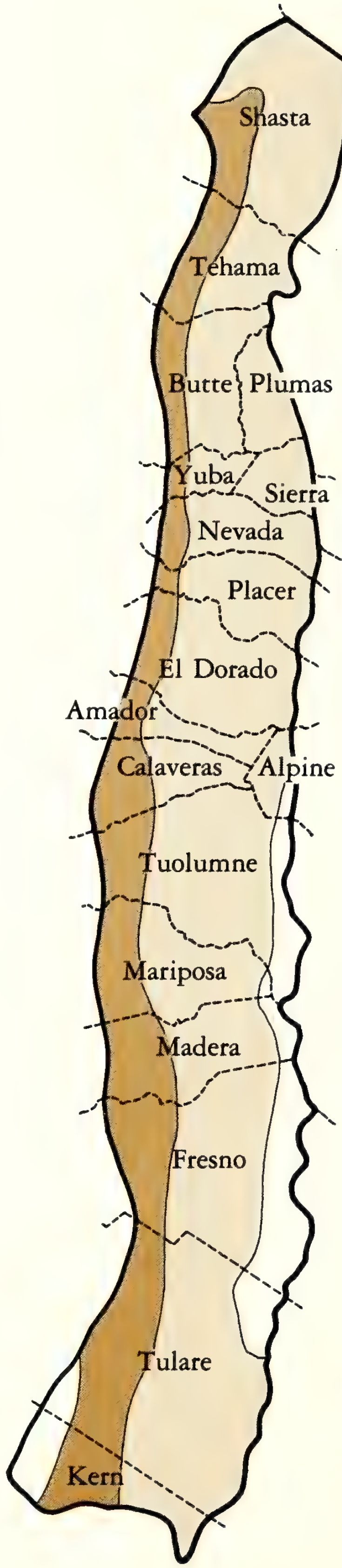
TERRITORY/HOME RANGE: No data on home range. In the Santa Monica Mountains, Stiles (1973) reported a range in defended area around nest from 50 to 100 ft (15 to 30 m) in diameter.

FOOD HABITS: Eats insects and nectar, from wide variety of flower sources. Probes flowers for nectar while hovering, gleans insects from foliage, and hawks for flying insects.

OTHER:

REFERENCES: Bent 1940, Grinnell and Miller 1944, Stiles 1973.





Anna's Hummingbird

B079 *(Calypte anna)*

STATUS: No official listed status. Common resident in suitable habitat.

DISTRIBUTION/HABITAT: Breeds from oak savannahs up to ponderosa pine and black oak woodland zone; prefers timbered sites with low percent canopy cover. In spring and summer, observed as high as the Jeffrey pine forests.

SPECIAL HABITAT REQUIREMENTS: Nectar source; small, medium, or large openings; water.

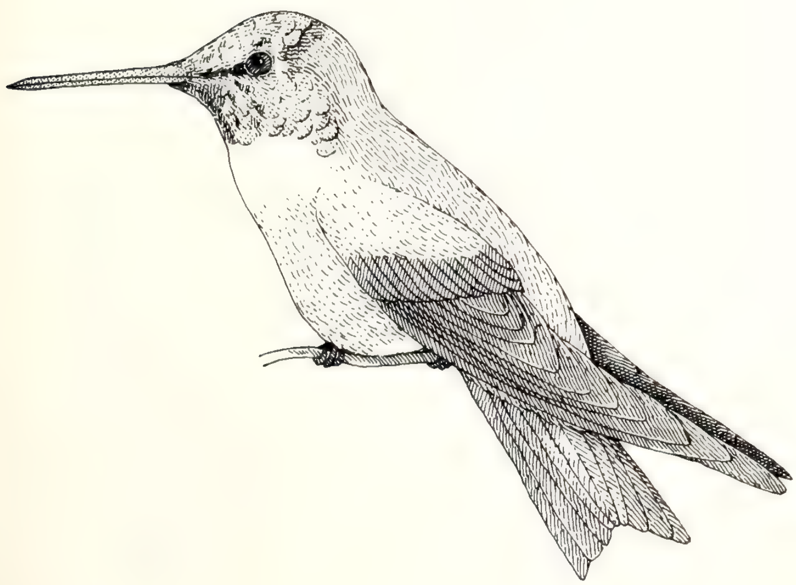
BREEDING: Breeds from mid-December to mid-June, with peak from mid-February to mid-May. Possibly three broods per season (Pitelka 1951b). Nests in trees or shrubs, from 5 to 30 ft (1.5 to 9.1 m) up. Typically, 2 eggs per clutch.

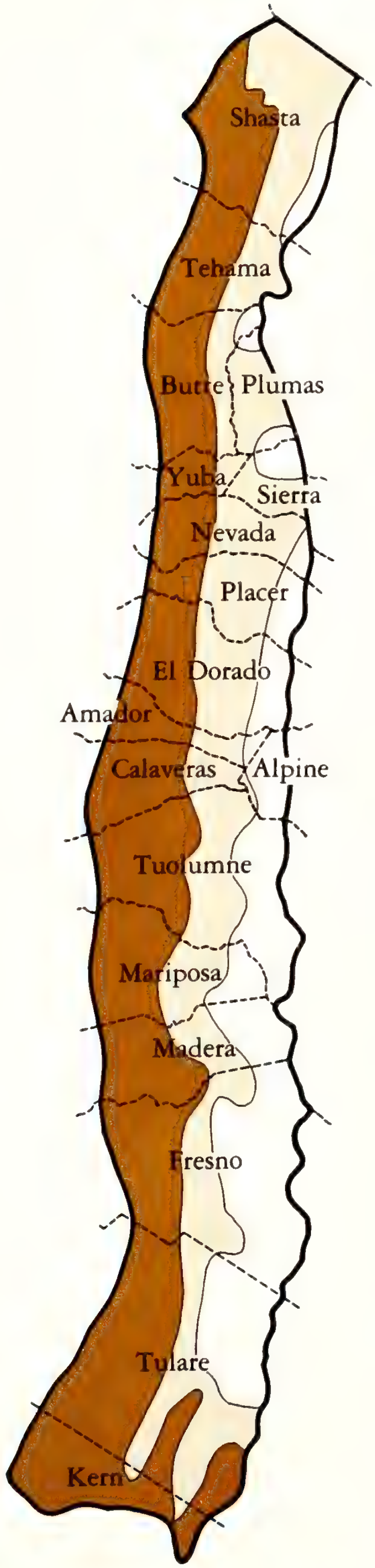
TERRITORY/HOME RANGE: No data on home range size. Size of territory, and vigor with which defended, vary with season and physiological state of male. Feeding territories defended in nonbreeding period, generally including several plants capable of supporting one bird for 1 day (Stiles 1973). During breeding season, most males establish large, actively defended territories (Williamson 1956). Average territory size 0.3 acre (0.1 ha) (Stiles 1973).

FOOD HABITS: Eats nectar from wide variety of flowers, especially *Ribes* spp.; also takes pollen and minute insects and spiders. Probes flowers while hovering, picks insects and spiders from flowers and foliage, and hawks aerial insects.

OTHER:

REFERENCES: Grinnell and Miller 1944, Pitelka 1951b, Stiles 1973.





Allen's Hummingbird

B080 *(Selasphorus sasin)*

STATUS: No official listed status. On basis of specimen records, an extremely rare late summer migrant; actual status unknown, but possibly regular at all elevations in fall (Gaines 1977).

DISTRIBUTION/HABITAT: Knowledge of distribution and abundance sketchy because cannot be distinguished from rufous hummingbird in most plumages (see comments below, under "OTHER"). Less common in the Sierra Nevada than rufous hummer (Gaines 1977). Found in open sites from digger pine-oak woodlands up to alpine meadows during summer months.

SPECIAL HABITAT REQUIREMENTS: Nectar source.

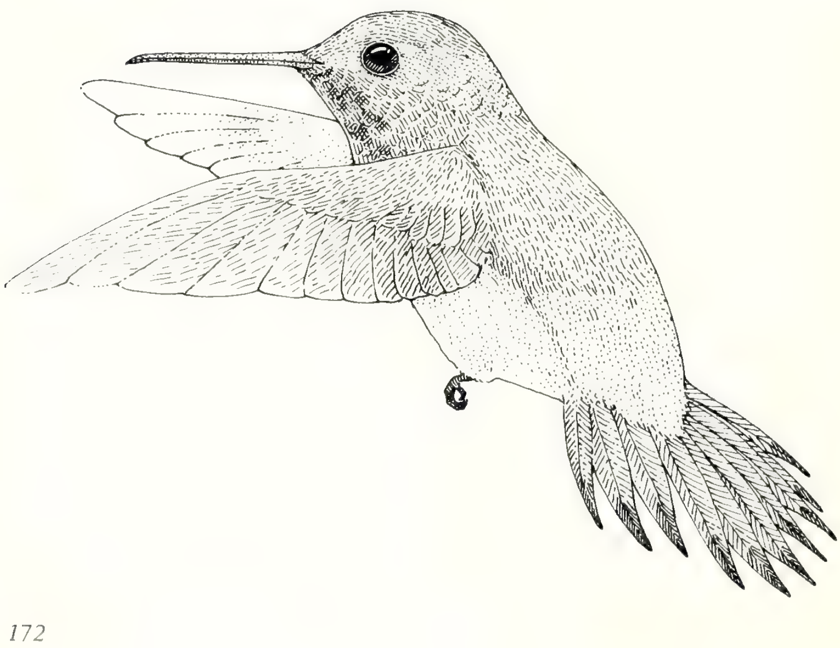
BREEDING: Nonbreeder in the Sierra Nevada.

TERRITORY/HOME RANGE: No data on home range or territory sizes.

FOOD HABITS: Eats nectar from wide variety of flowers, also eats some insects. Probes flowers while hovering, gleans insects from flowers and foliage, and hawks for aerial insects.

OTHER: Adult males distinguished from adult male rufous hummingbirds by all-green back; back of male rufous hummer mostly rufous, perhaps with some green feathers (Stiles 1972).

REFERENCES: Bent 1940, Grinnell and Miller 1944, Pitelka 1951b.



Rufous Hummingbird

B081 *(Selasphorus rufus)*

STATUS: No official listed status. Common spring transient at low elevations; fall transient at middle and high elevations.

DISTRIBUTION/HABITAT: During spring migration, found in grass/forb, shrub, and sparsely timbered areas from annual grasslands up to ponderosa pine and black oak woodland zone. Southward migrants tend to be higher, even up into alpine meadows.

SPECIAL HABITAT REQUIREMENTS: Nectar Source.

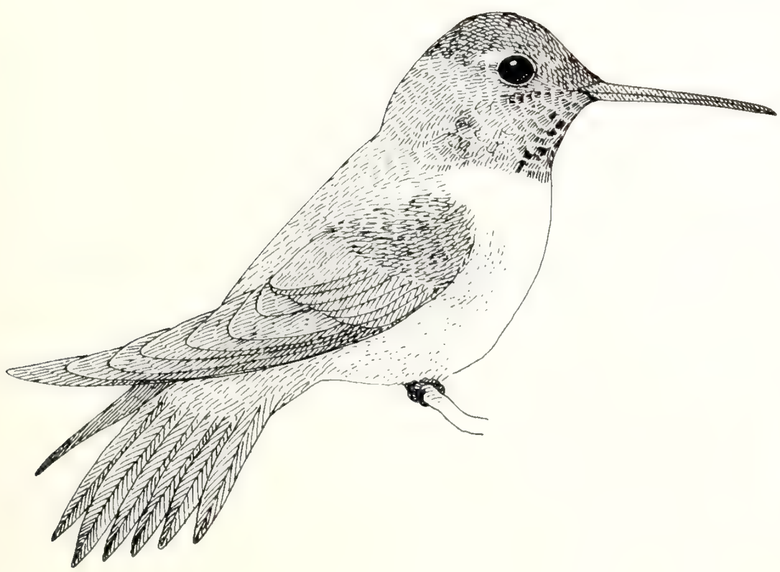
BREEDING: Does not breed in the western Sierra Nevada, although early literature suggests it does. Confusion because spring migration generally continues until May; males begin return southward migration as early as June, because they do not assist with raising young in northern breeding grounds.

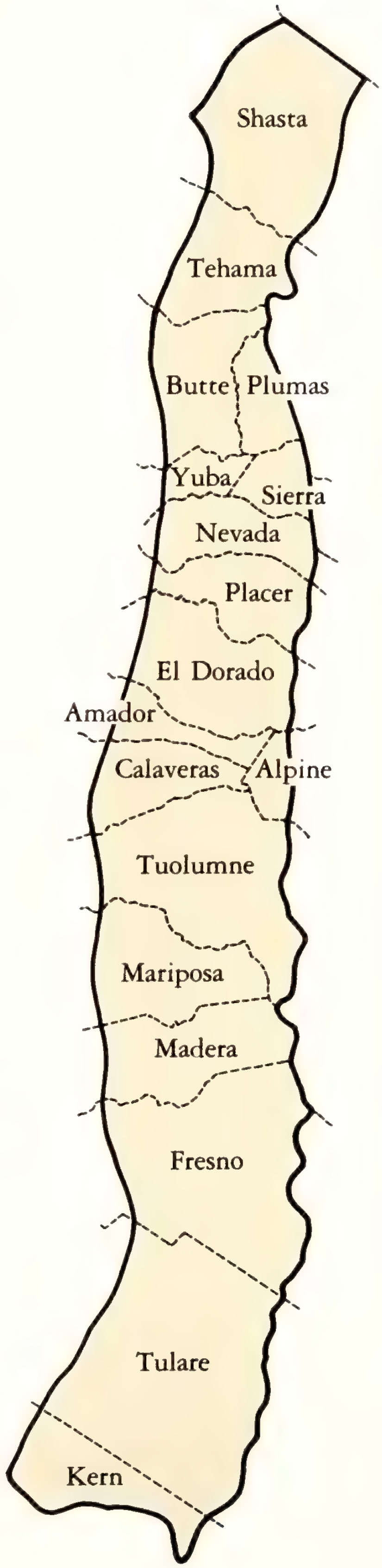
TERRITORY/HOME RANGE: Defends feeding territories, but unknown whether or not they do so while migrating through the Sierra Nevada. In Yellowstone National Park, five feeding territories actively defended in area about 20 by 50 ft (6.1 by 15 m) (Armitage 1955).

FOOD HABITS: Eats nectar from wide variety of flowers, especially *Ribes* spp.; also takes some insects. Probes flowers while hovering, gleans insects from flowers and foliage, and hawks aerial insects.

OTHER:

REFERENCES: Grinnell and Storer 1924, Bent 1940, Grinnell and Miller 1944.





Calliope Hummingbird

B082 *(Stellula calliope)*

STATUS: No official listed status. Uncommon spring migrant and summer resident.

DISTRIBUTION/HABITAT: Breeds from ponderosa pine and black oak woodland zone up to lodgepole pine forests. Prefers timbered stands with low to intermediate percent canopy cover, near water. In spring, migrates through lower elevations as low as digger pine-oak type.

SPECIAL HABITAT REQUIREMENTS: Nectar source; water.

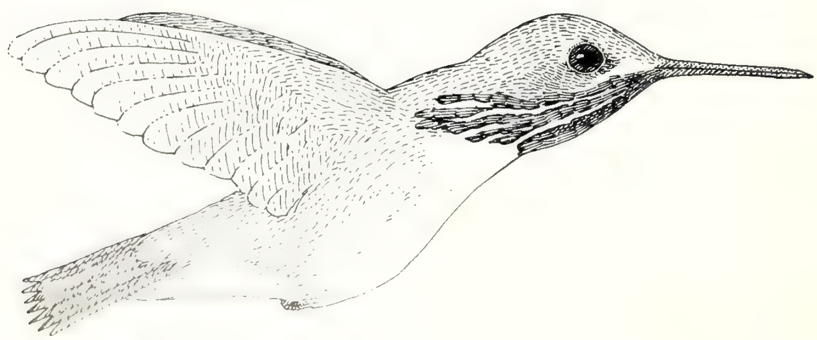
BREEDING: Breeds from early May to late July, with peak from early June to early July. Nesting generally coincides with blooming of wild currant. Nests almost always in a lodgepole pine or aspen, immediately beneath live branches, and typically in riparian area. Nest height ranges from 10 to 30 ft (3 to 9 m). Mean clutch size 2.

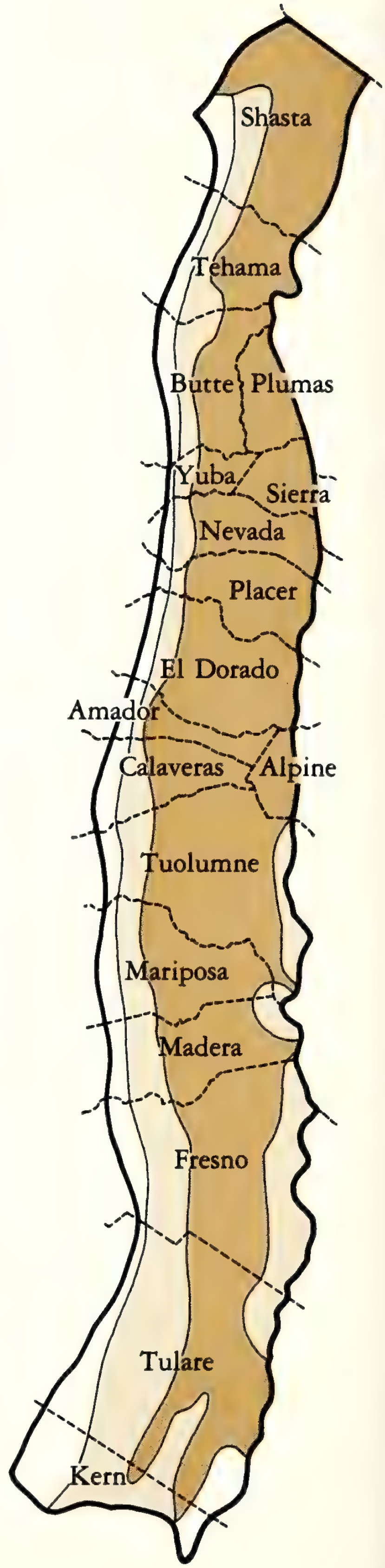
TERRITORY/HOME RANGE: No data on home range. Nesting density in Lassen County, four pairs per 6 acres (2.4 ha) (Grinnell *et al.* 1930). Each male vigorously defends patch of wild currant in early nesting season.

FOOD HABITS: Eats nectar from variety of flowers, including gooseberry, currant and manzanita, by hovering and probing. Also hawks for flying insects.

OTHER: Only hummingbird species that regularly nests at middle and high elevations in western Sierra Nevada.

REFERENCES: Grinnell and Storer 1924, Bent 1940, Calder 1971.





Belted Kingfisher

B083 *(Megaceryle alcyon)*

STATUS: No official listed status. Uncommon resident.

DISTRIBUTION/HABITAT: Found in all vegetation types and successional stages except alpine meadows; breeds from annual grassland zone up to Jeffrey pine forests, but restricted to streamside or lakeside situations. Moves southward and downslope in fall and winter; some move upslope to treeline in late summer and early fall. Most breeding records in the Sierra Nevada from Kings Canyon region northward; most winter records from that region southward.

SPECIAL HABITAT REQUIREMENTS: Earthen bank for nesting; pond, lake, stream, or river for feeding.

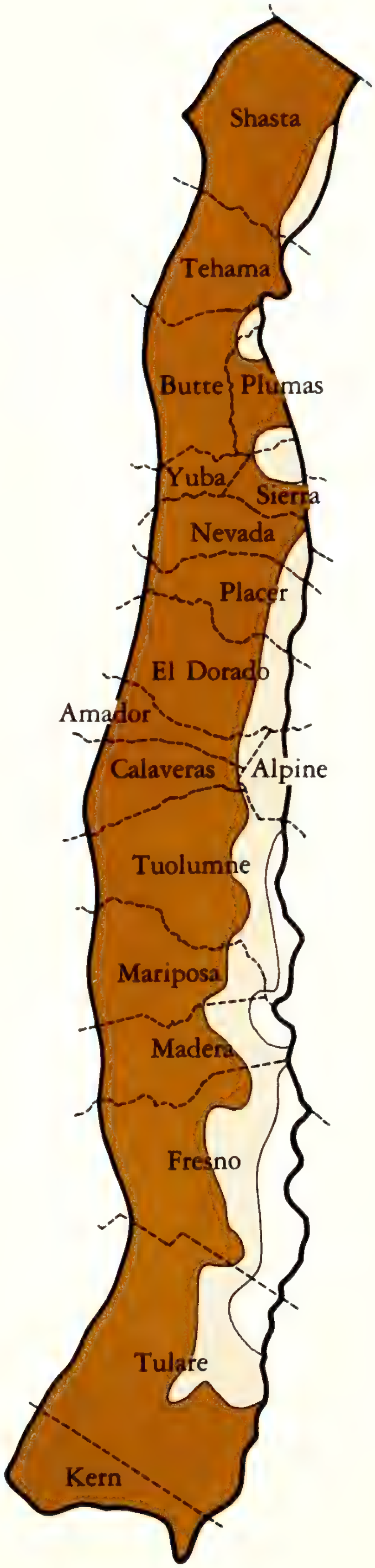
BREEDING: Breeds from early April to early August, with peak from late April to late June. Nests in burrow excavated by birds themselves in sandy or earthen bank, usually by edge of water. Burrow opening usually within 2 ft (0.6 m) of top of bank, and usually more than 5 ft (1.5 m) above water surface. Clutch size from 5 to 11, usually 6 or 7.

TERRITORY/HOME RANGE: In Michigan, stayed within 0.5 to 3 mi (0.8 to 4.8 km) of shoreline during breeding season (Salyer and Lagler 1946). In Minnesota, pairs ranged from 2 to 5 mi (3.2 to 8 km) along a stream course (Cornwell 1963).

FOOD HABITS: Adult eats fish and crayfish but feeds young nestlings on insects. Dives from a perch or a hovering position, 20 to 50 ft (6.1 to 15 m) above water surface, capturing prey usually within 2 ft (0.6 m) below water surface. Prefers to hunt in shallow, slow-moving streams or in lakes.

OTHER: Not important predators on trout except at fish hatcheries, where fish can be protected by screens.

REFERENCES: Salyer and Lagler 1946, White 1953, Cornwell 1963.



Common Flicker

B084 *(Colaptes auratus)*

STATUS: No official listed status. Common permanent resident.

DISTRIBUTION/HABITAT: Usually versatile in habitat selection; breeds in all forest types in the western Sierra Nevada. Prefers low stand densities with large, scattered trees. Usually stays below snowline in winter; some may linger high in the mountains.

SPECIAL HABITAT REQUIREMENTS: Snags or trees with soft heartwood.

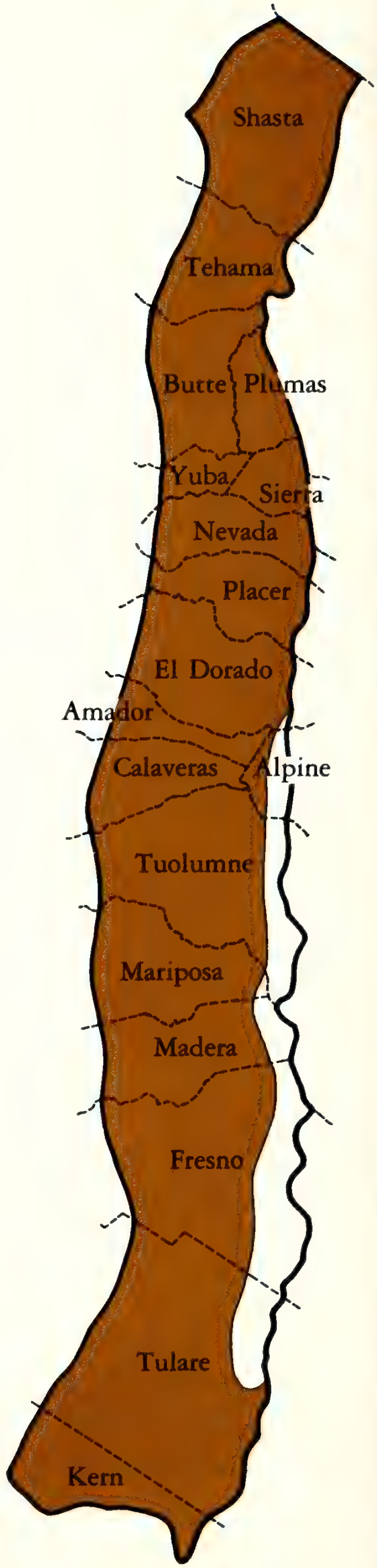
BREEDING: Breeds from mid-April to late July, with peak activity from late May to late June. Clutch size from 5 to 12, with 6 or 7 most common. As cavity nesters, excavate own cavities in tree trunks with soft wood, whether dead or alive. Occasionally use posts or holes in banks. Height ranges from 0 to 100 ft (0 to 30 m).

TERRITORY/HOME RANGE: In Ontario, territories averaged 40 acres (16 ha) in mature conifer forest during breeding season (Lawrence 1967). Home range and territory the same; presence of territories in winter not reported in the literature.

FOOD HABITS: Omnivorous, eating ants, seeds, miscellaneous insects, fruits, and berries. Feeds mainly on ground, rarely on bark; digs with bill, and gleans from surfaces.

OTHER: Roosts year-round in hole similar to nest sites.

REFERENCES: Jackman and Scott 1975, Kilham 1959, Lawrence 1967.



Pileated Woodpecker

B085 *(Dryocopus pileatus)*

STATUS: No official listed status, though probably declining as a result of logging of mature forests with snags.

DISTRIBUTION/HABITAT: Generally distributed in conifer forest from ponderosa pine to red fir types; prefers at least 40 percent canopy cover and mature trees. Prefers Douglas-fir, white fir, and, occasionally, red fir over all other conifers.

SPECIAL HABITAT REQUIREMENTS: Large snags; low human disturbance.

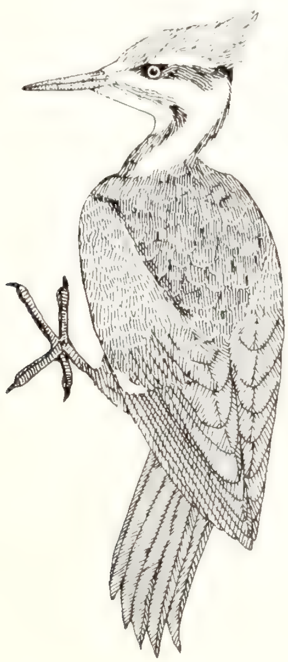
BREEDING: Breeds from early March to early July, with peak activity from early May to mid-June. Clutch size 3 or 4 eggs laid in large cavity of dead conifer or large aspen averaging 1.6 ft (0.5 m) in diameter. Excavates own cavities from 15 to 70 ft (4.6 to 21 m) up.

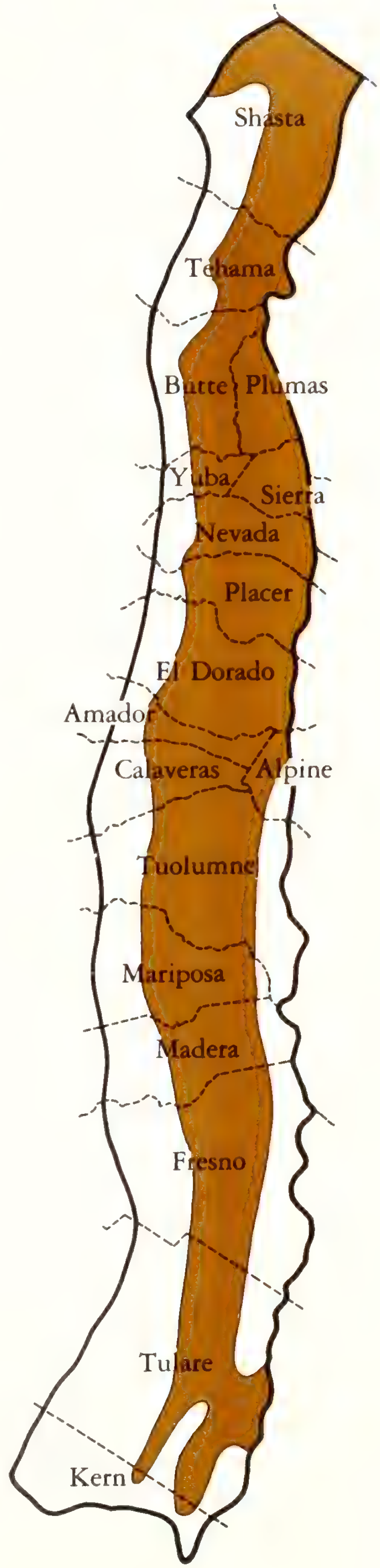
TERRITORY/HOME RANGE: Territory size not known. In Ithaca, New York, home range, estimated year-round, had radius of 3 to 4 mi (4.8 to 6.4 km) in mixed forest of deciduous and coniferous trees (Hoyt 1957). In conifer forests of northeastern Oregon, ranged over 320 to 600 acres (130 to 243 ha); minimum density of 13 pairs was 1 pair per 1620 acres (656 ha) (Bull and Meslow 1977).

FOOD HABITS: Eats insects, especially carpenter ants; also fruits and nuts. Obtains much food by deep excavation in decaying wood on standing trees or fallen logs, usually within 10 ft (3 m) of the ground.

OTHER: Drills the largest of woodpecker holes; may be sole provider of nest cavities for tree-nesting ducks, such as bufflehead, wood duck, and common merganser. Recommend leaving 90 snags, plus replacement snags, per section (256 ha), all at least 20 in (51 cm) d.b.h. (Bull and Meslow 1977).

REFERENCES: Hoyt 1957, Jackman and Scott 1975, Bull and Meslow 1977.





Acorn Woodpecker

B086 *(Melanerpes formicivorous)*

STATUS: No official listed status. Continued elimination of oaks in California a serious threat to this species' continued presence.

DISTRIBUTION/HABITAT: Strictly confined to stands with oaks, breeds from blue oak savannahs up into black oak woodlands and ponderosa pine forests. Prefers lower elevations and stands with lower tree densities. In fall, may wander upslope into mixed-conifer forests where black oaks occur.

SPECIAL HABITAT REQUIREMENTS: Oaks; large trees for acorn storage.

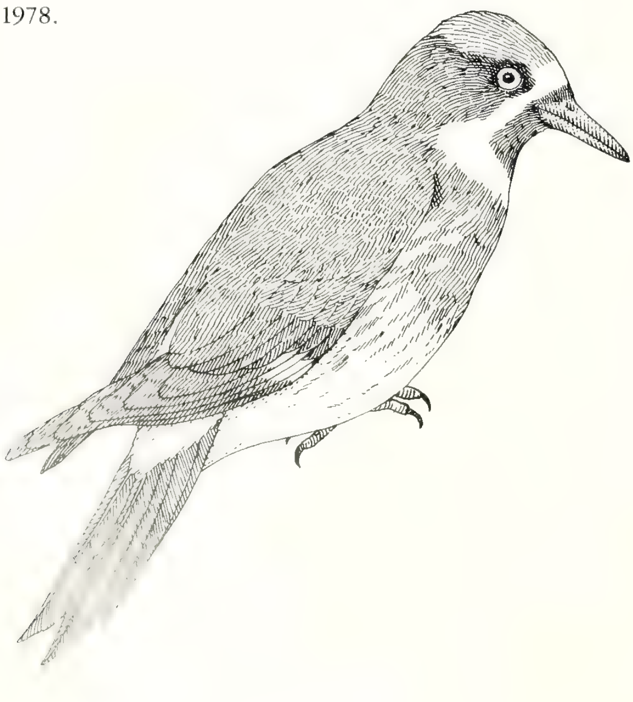
BREEDING: Breeds from early April to late July, with peak from mid-May to late June. Clutch size from 4 to 6, most contain 4 or 5 eggs. Excavates own nest cavity in live or dead oaks, in sycamores, or in dead conifers, from 6 to 70 ft (1.8 to 21 m) up.

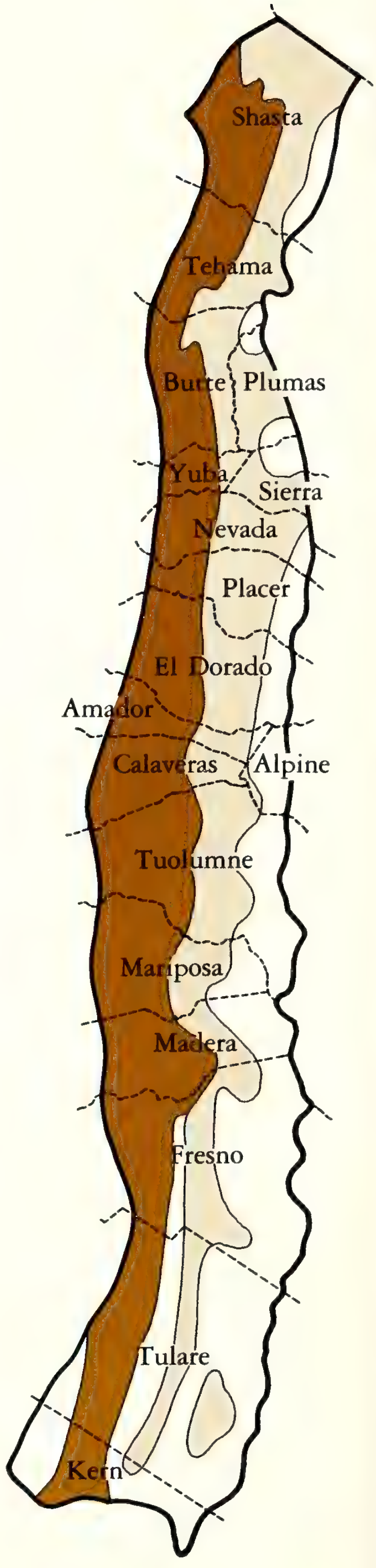
TERRITORY/HOME RANGE: Territory and home range the same. In Monterey County, territory ranged from 9 to 23 acres (3.6 to 9.3 ha) and averaged 15 acres (6.1 ha) (MacRoberts and MacRoberts 1976). In Yolo County, Swearingen (1977) cites Roberts (pers. commun.) as finding territories ranging in size from 3.7 to 19.8 acres (1.5 to 8.0 ha), with mean of 11.4 acres (4.6 ha). In San Mateo County, Swearingen (1977) reported territory sizes from 2.2 to 10.6 acres (0.9 to 4.3 ha), with mean of 5.9 acres (2.4 ha).

FOOD HABITS: Eats mostly acorns, flying insects, and sap. Picks acorns from trees and stores in individual holes drilled in snags, posts, telephone poles, and thick bark of live trees. Hawks for insects and drills holes in live trees to obtain sap.

OTHER: Food storage behavior frequently damages fence posts and telephone poles to the extent they must be replaced. Recommend traditional acorn storage trees and nearby large oaks never be cut.

REFERENCES: MacRoberts 1970, MacRoberts and MacRoberts 1976, Gutierrez and Koenig 1978.





Lewis' Woodpecker

B087 *(Melanerpes lewis)*

STATUS: No official listed status; on the Audubon Society Blue List for 1978. A nonbreeding visitor to the western Sierra Nevada from August to May. Source of visitors uncertain; however, species breeds east of the Sierra Nevada crest, and may migrate across mountains into the western Sierran zone. Some old nesting records exist from southern end of the western Sierra Nevada.

DISTRIBUTION/HABITAT: Found from blue oak savannahs up to Jeffrey pine forests. Prefers stands of low to intermediate density. Opportunistic and of erratic occurrence in any given area. Brushfields optimal habitat, providing scattered live or dead trees available for foraging perches. Favors old burns with tall standing snags or poles above brushfields.

SPECIAL HABITAT REQUIREMENTS: Oaks in fall and winter.

BREEDING: Apparently does not breed in the western Sierra Nevada today (Bock 1970).

TERRITORY/HOME RANGE: Fall and winter territories established in areas with sufficient supply of acorns and insects. Defends only immediate vicinity of acorn storage site.

FOOD HABITS: Eats primarily adult insects; acorns important in winter, also berries and fruit. Picks acorns from trees; hawks for insects, also drops from perch to lower vegetation to capture insects.

OTHER:

REFERENCES: Bock 1970, Jackman and Scott 1975.

Yellow-bellied Sapsucker

B088 *(Sphyrapicus varius)*

STATUS: No official listed status. Common resident on the west slopes of the Sierra Nevada, with pronounced altitudinal migration.

DISTRIBUTION/HABITAT: Breeds in timbered stands of low to intermediate density in ponderosa pine, black oak, riparian deciduous, and mixed-conifer types; strongly prefers to nest in deciduous trees along water courses. In summer, feeds as high up as lodgepole forests; in winter, found as low as blue oak savannahs.

SPECIAL HABITAT REQUIREMENTS: Snags or trees with soft heartwood for cavity excavation.

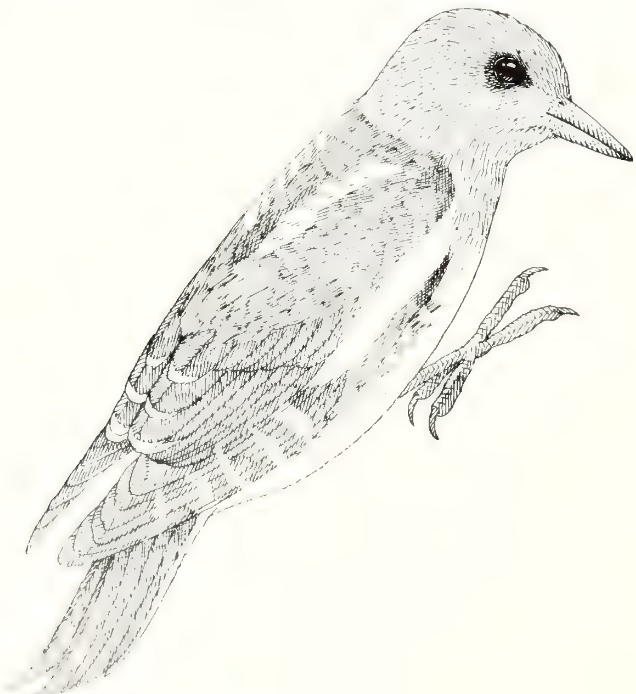
BREEDING: Breeds from early May to late July, with peak from early June to early July. Clutch size from 4 to 6, most contain 4 or 5. Excavates own nest cavity in dead trees or live trees with rotted heartwood, from 15 to 60 ft (4.6 to 18 m) above ground.

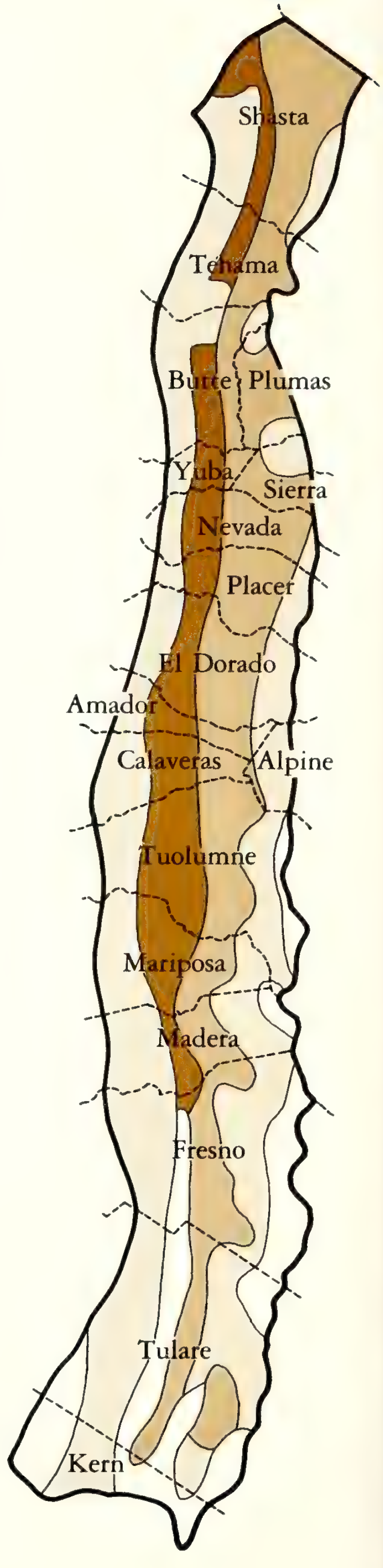
TERRITORY/HOME RANGE: In British Columbia study, Howell (1952) reported range in territory size from 1.6 to 15 acres (0.7 to 6.1 ha). In Ontario, Lawrence (1967) indicated home range and territory the same, averaging 5.3 acres (2.1 ha) in a mature conifer forest (range from 5.1 to 5.4 acres [2.1 to 2.2 ha]).

FOOD HABITS: Eats primarily cambium, soft parts of tree trunks, sap, insects, and fruit; mainly ants during breeding season. Drills for and eats sap; hawks for insects.

OTHER: Classification of this complex undecided, with some ornithologists recognizing three different species. Almost all in the western Sierra Nevada are members of a red-breasted form (*S.v. daggeti,* American Ornithologists' Union 1957), but a form with more red on the head (*S. v. ruber,* American Ornithologists' Union 1957) also occurs.

REFERENCES: Howell 1952, Lawrence 1967, Devillers 1970.





Williamson's Sapsucker

B089 *(Sphyrapicus thyroideus)*

STATUS: No official listed status. Fairly common resident.

DISTRIBUTION/HABITAT: Breeds in Jeffrey pine, red fir, and especially in lodgepole pine forests. Prefers sites with large trees and low to intermediate percent canopy coverage. Winter distribution poorly known; at least part of population moves downslope into ponderosa pine and mixed-conifer forests.

SPECIAL HABITAT REQUIREMENTS: Snags.

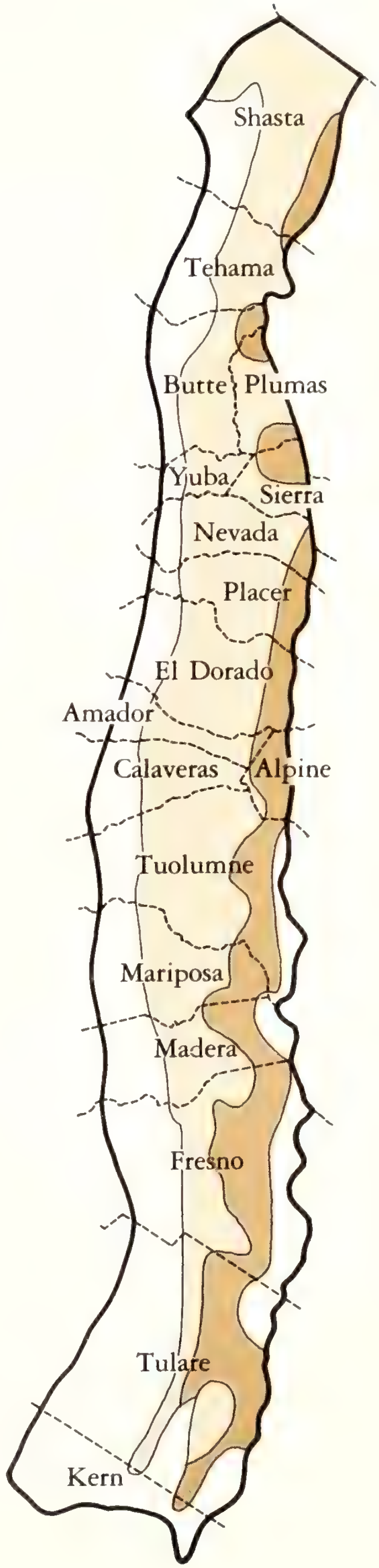
BREEDING: Breeds from late April to late July, with peak from late May to mid-July. Nests usually in old lodgepole pine with a dead core; also nests in other conifer types (Granholm, unpubl.). In Colorado, however, most nests found in aspen (Crockett 1975, Crockett and Hadow 1975). Excavates own nest cavity, from 5 to 60 ft (1.5 to 18 m) up. Clutch contains from 3 to 7 eggs, with 5 or 6 most frequent.

TERRITORY/HOME RANGE: Home range in breeding season the same as territory. In the Colorado Rockies, Crockett (1975) found a range in territory size from 10 to 22.5 acres (4.1 to 9.1 ha), with a mean of 16.9 acres (6.8 ha).

FOOD HABITS: Eats ants when feeding young; at other times of year eats sap and sapwood of conifers; may eat wood-boring insects during winter. Obtains most food from trunks and limbs of living conifers, from the ground, and from downed logs. Gleans insects and bores into live trees to obtain sap.

OTHER:

REFERENCES: Bent 1939, Grinnell and Miller 1944, and Crockett 1975.



Hairy Woodpecker

B090 (*Picoides villosus*)

STATUS: No official listed status. Fairly common permanent resident in suitable habitat.

DISTRIBUTION/HABITAT: Prefers, for breeding habitat, stands of large mature trees, of sparse to intermediate stand density, from ponderosa forests upslope to lodgepole pine forests. In fall and winter, some move down into digger pine-oak woodlands. Often numerous in recently burned areas.

SPECIAL HABITAT REQUIREMENTS: Snags.

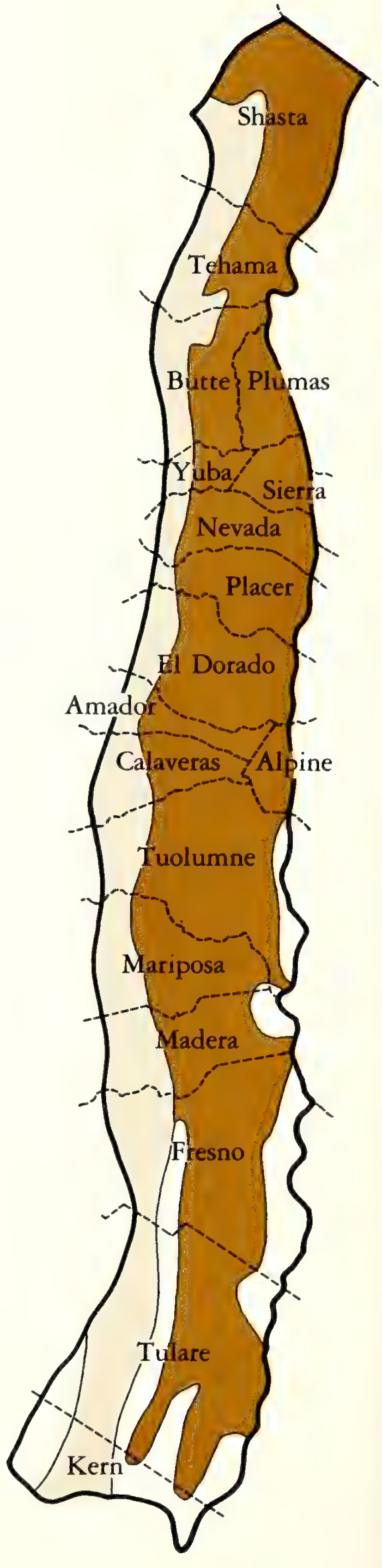
BREEDING: Breeds from mid-March to late August, with peak from late May to mid-July. Clutch size from 3 to 6 eggs, with 4 most frequent. Excavates own nest cavity, from 3 to 50 ft (0.9 to 15 m) up, in dead tree or live tree with dead heartwood.

TERRITORY/HOME RANGE: Territory and home range the same. In a mature coniferous forest in Ontario, territory size ranged from 6 to 8 acres (2.4 to 3.2 ha) (Lawrence 1967).

FOOD HABITS: Eats primarily insect larvae, ants, and pine seeds. Obtains food by drilling into bark of dead trees, logs, and less often into live trees. Picks pine seeds from cones.

OTHER:

REFERENCES: Lawrence 1967, Kilham 1970.



Downy Woodpecker

B091 *(Picoides pubescens)*

STATUS: No official listed status. Locally common resident in suitable habitat.

DISTRIBUTION/HABITAT: Breeds in riparian woodlands associated with low elevation oak and pine/oak forests and upward into ponderosa pine and black oak types. Occasionally feeds in adjacent oak or coniferous forests. Wanders upslope in late summer as high as 7800 ft (2380 m).

SPECIAL HABITAT REQUIREMENTS: Snags or trees with soft heartwood.

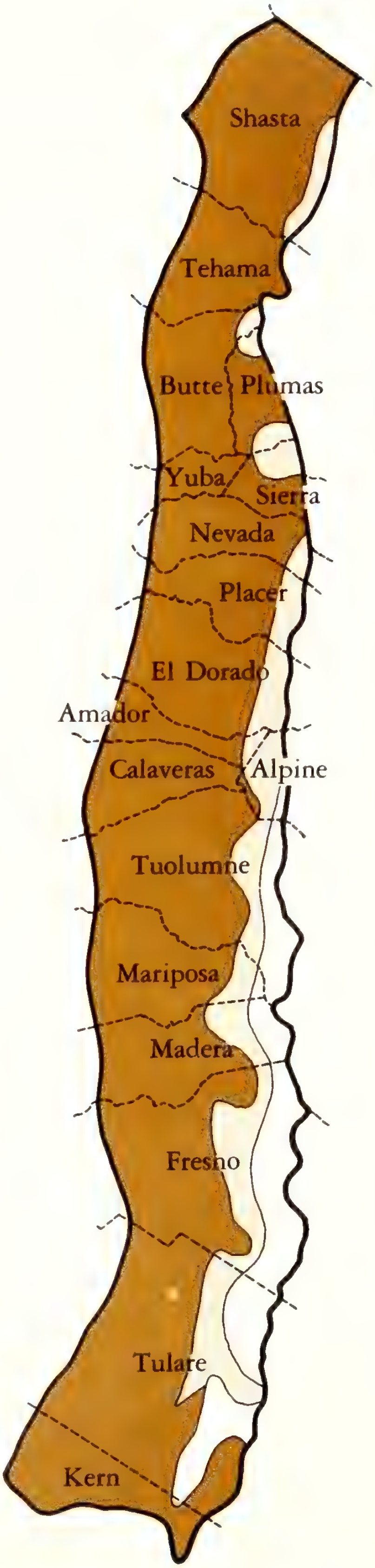
BREEDING: Breeds from early April to early September, with peak from early May to mid-June. Clutch size from 3 to 6, 4 or 5 most common. Excavates own nest cavity, 4 to 20 ft (1.6 to 6.1 m) up, in decaying branch or tree trunk.

TERRITORY/HOME RANGE: Territory and home range the same. Two territories in a mature conifer forest in Ontario were 5 and 8 acres (2 and 3.2 ha) in size (Lawrence 1967).

FOOD HABITS: Obtains adult and larval insects from bark of small tree trunks and branches, living or dead, by gleaning and probing.

OTHER:

REFERENCES: Kilham 1962, 1970; Lawrence 1967.



Nuttall's Woodpecker

B092 *(Picoides nuttallii)*

STATUS: No official listed status. Fairly common permanent resident in suitable habitats.

DISTRIBUTION/HABITAT: Most often found in riparian vegetation bordered by or mixed with oaks. Prefers oaks for foraging and riparian trees for nests. Some move upslope in late summer and fall, regularly to 4000 ft (1220 m) and sometimes to 7000 ft (2130 m), usually in riparian habitats.

SPECIAL HABITAT REQUIREMENTS: Snags.

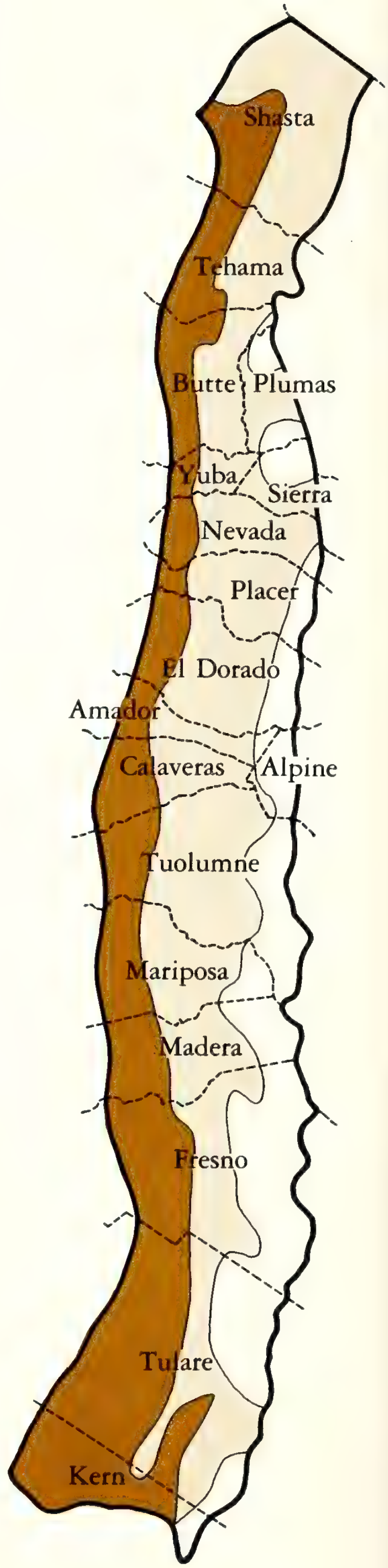
BREEDING: Breeds from late March to late June, with peak from early May to early June. Clutch size from 3 to 6, with mean of 4.6. Excavates own nest cavity, from 2.5 to 60 ft (0.8 to 18 m) up, usually in dead tree trunk or limb (occasionally live).

TERRITORY/HOME RANGE: Only estimate from a study by Miller and Bock (1972) in Monterey County where average home range, estimated year-round, was a riparian strip about 0.5 mi (800 m) long.

FOOD HABITS: Feeds mainly on insects; also takes some fruits, berries, and seeds. Obtains food mainly from trunks, branches, and twigs, by surface gleaning, probing, and twig scanning. Also excavates, eats sap, and even hawks flying insects.

OTHER.

REFERENCES: Miller and Bock 1972.



White-headed Woodpecker

B093 *(Picoides albolarvatus)*

STATUS: No official listed status. Common permanent resident.

DISTRIBUTION/HABITAT: Found in conifer forests from ponderosa pine type up to red fir type; prefers areas with large trees providing 40 to 70 percent canopy coverage.

SPECIAL HABITAT REQUIREMENTS: Snags.

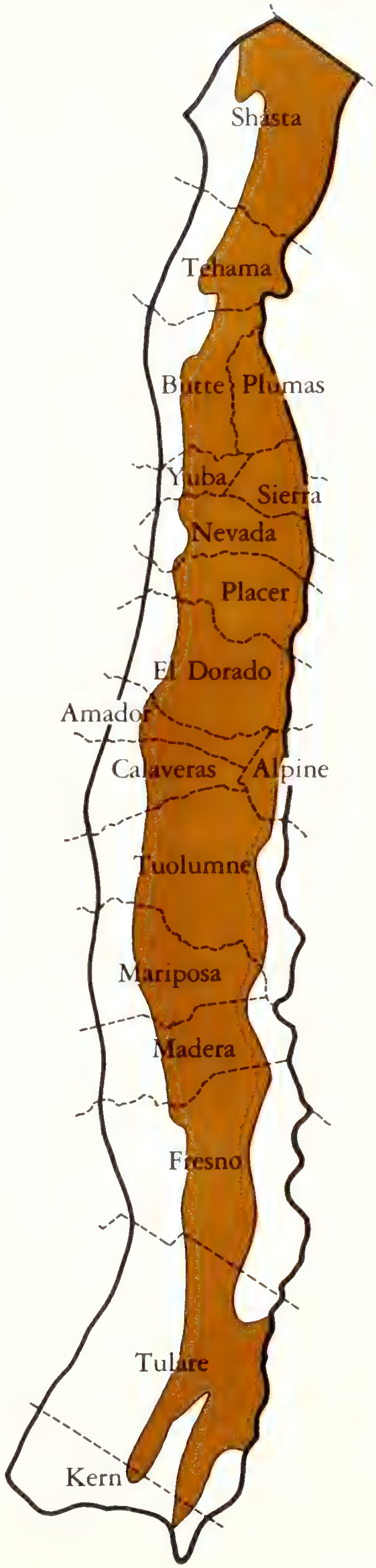
BREEDING: Breeds from mid-April to late August, with peak from mid-June to mid-July. Clutch size from 3 to 7, most contain 4. Excavates cavities in dead trees, or even in stumps, generally close to the ground.

TERRITORY/HOME RANGE: No data available.

FOOD HABITS: Pine seeds make up 60 percent and insects 40 percent of diet (on an annual basis). Chips open pine cones to obtain seeds; gleans insects from needles or picks them from under bark flakes that are pried loose.

OTHER:

REFERENCES: Ligon 1973, Jackman and Scott 1975.



Black-backed Three-toed Woodpecker

B094 *(Picoides arcticus)*

STATUS: No official listed status. Uncommon to rare resident in forests at higher elevations; moves into lower elevations in fall, winter, and spring.

DISTRIBUTION/HABITAT: Breeds in red fir and lodgepole pine forests; prefers stands with large trees; stand density not too important. In fall, winter, and spring may be found in all conifer types down to ponderosa pine.

SPECIAL HABITAT REQUIREMENTS: Snags or trees with soft heartwood.

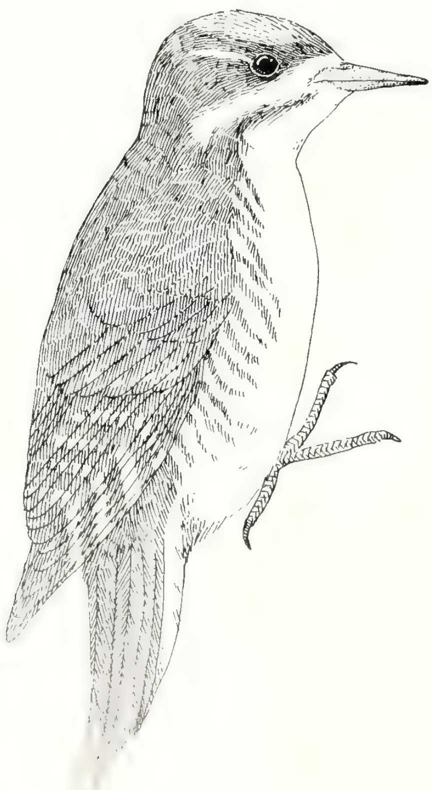
BREEDING: Breeds from early May to early September, with peak from mid-June to late July. Clutch size from 2 to 6, most consist of 4. Excavates nest cavities from 2 to 80 ft (0.6 to 24 m) and usually from 10 to 20 ft (3.1 to 6.1 m) up, in live or dead tree trunks.

TERRITORY/HOME RANGE: No data available.

FOOD HABITS: Eats primarily insect larvae and adults, obtained by scaling away bark or by drilling into the trunk of live or dead trees.

OTHER: Life history is not well known, especially in Western United States. Specific habitat requirements in the Sierra Nevada unclear; apparently prefers burns, windfalls, or other areas with wood-boring insect infestations. Common forestry practices to prevent such infestations harmful to this species.

REFERENCES: Mayfield 1958, Bock and Bock 1974, Short 1974.



Western Kingbird

B095 *(Tyrannus verticalis)*

STATUS: No official listed status. Common spring migrant and summer resident; usually leaves the western Sierra Nevada by late summer.

DISTRIBUTION/HABITAT: Breeds in arid, low elevation habitats with low to intermediate canopy coverage.

SPECIAL HABITAT REQUIREMENTS: Elevated perches.

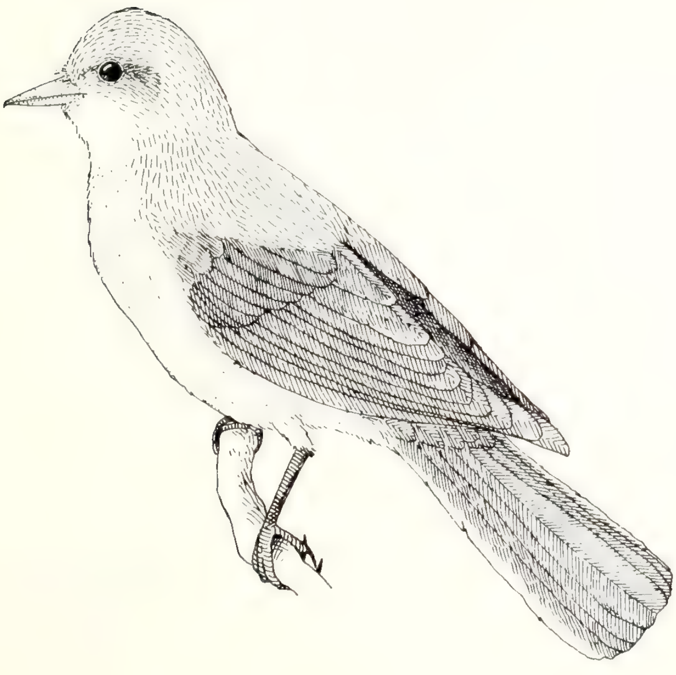
BREEDING: Breeds from early April to early July, with peak from mid-May to early June. Nests from 15 to 30 ft (4.6 to 9.1 m) up on a horizontal branch of oak, cottonwood, or willow. Clutch size from 3 to 5, with mean of 4.

TERRITORY/HOME RANGE: No good information available, although Hespenheide (1964) indicates will forage at least 0.25 mi (400 m) from the nest.

FOOD HABITS: Eats primarily insects; also some seeds. Captures insects in flight, by hawking from low, conspicuous branches.

OTHER: Although largely restricted to low elevations, altitudinal vagrants observed to 8500 ft (2590 m) in Tuolumne Meadows, Yosemite National Park.

REFERENCES: Grinnell and Storer 1924, Whedon 1938, Smith 1966, Ohlendorf 1974.



Ash-throated Flycatcher

B096 *(Myiarchus cinerascens)*

STATUS: No official listed status. Fairly common summer resident at lower elevations.

DISTRIBUTION/HABITAT: Breeds in shrublands and timbered sites from blue oak savannah up to ponderosa pine and black oak woodland types; prefers stands with low percent canopy coverage.

SPECIAL HABITAT REQUIREMENTS: Natural tree cavities.

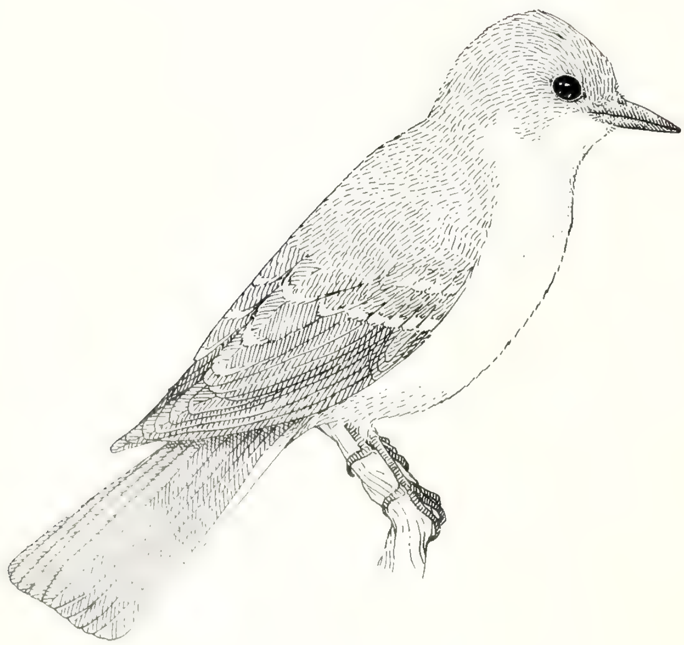
BREEDING: Breeds from mid-April to late June, with peak from mid-May to early June. Nests usually in knotholes of oaks or cottonwoods, but sometimes in old stumps or woodpecker holes. Nests as much as 20 ft (6.1 m) above ground. Clutch size from 3 to 7, with mean of 4.

TERRITORY/HOME RANGE: No data on home range, but Hensley (1954) reported a territory in a desert wash at 7.3 acres (3.0 ha) and another in open desert at 24.7 acres (10 ha).

FOOD HABITS: Feeds primarily on insects; also eats some berries and seeds. Hawks for aerial insects from conspicuous perches; also gleans insects from foliage, generally by flying upward from perch and snapping insect from leaf surface.

OTHER: Though normally restricted to arid foothills and chaparral-covered canyons at lower elevations, has been noted, exceptionally, at 9700 ft (2960 m) in Yosemite National Park.

REFERENCES: Bent 1942, Small 1974.



Black Phoebe

B097 *(Sayornis nigricans)*

STATUS: No official listed status. Fairly common to common resident in riparian habitats throughout most of State, up to about 4000 ft (1220 m).

DISTRIBUTION/HABITAT: Restricted for breeding to riparian deciduous or lake margin habitat in low to mid-elevation ranges, and occasionally in wet meadows from 4000 to 5000 ft (1220 to 1520 m). Altitudinal vagrants observed to 8600 ft (2620 m) in Tuolumne Meadows, Yosemite National Park.

SPECIAL HABITAT REQUIREMENTS: Water source; cliffs, old buildings, or bridges for nesting.

BREEDING: Breeds from early March to mid-July, with peak from mid-April to mid-June. Nests on steep cliffs, walls of old buildings or bridges, or often under eaves. Height varies with substrate. Clutch size from 3 to 7, with mean of 4.

TERRITORY/HOME RANGE: No information available.

FOOD HABITS: Eats mainly flying insects, captured over grassy fields or open water. Captures aerial insects by hawking from perch; occasionally gleans insects from foliage.

OTHER: Tends to wander widely during prenesting season, but during nesting period restricted to area around nest.

REFERENCES: Oberlander 1939, Verbeek 1975, Ohlendorf 1976.

Say's Phoebe

B098 *(Sayornis saya)*

STATUS: No official listed status. Common to abundant resident in appropriate annual grassland areas, though only spring and summer visitor in upslope habitat types.

DISTRIBUTION/HABITAT: Breeds in all habitat types up to about 4000 ft (1220 m), except in riparian deciduous. Elevational vagrants recorded as high as 7000 ft (2130 m) in Yosemite National Park. Prefers sites with little shrub or tree cover.

SPECIAL HABITAT REQUIREMENTS: Crevices, old buildings, or bridges for nesting.

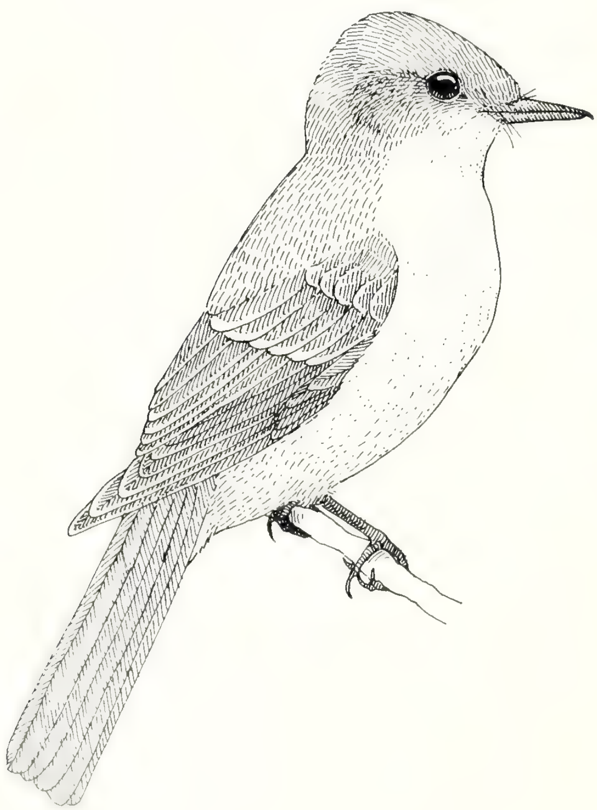
BREEDING: Breeds from early March to late July, with peak from mid-April to mid-June. Often produces two broods per season. Nests usually on walls of old buildings, under eaves; also on cliffs, steep river banks, or under bridges; rarely in tree cavities. Clutch size 3 to 7, with mean of 5.

TERRITORY/HOME RANGE: No information on home range.

FOOD HABITS: Eats mostly flying insects, captured by hawking from low perches.

OTHER:

REFERENCES: Phillips 1955, Ohlendorf 1976, Gaines 1977.



Willow Flycatcher

B099 *(Empidonax traillii)*

STATUS: No official listed status. Rare to uncommon summer resident; declined markedly in recent years because of destruction of riparian deciduous habitat, and nest parasitism by brown-headed cowbirds (Gaines 1977).

DISTRIBUTION/HABITAT: Breeds in low to middle elevations of riparian deciduous habitats and wet meadows with willow thickets, generally below 7000 ft (2130 m).

SPECIAL HABITAT REQUIREMENTS: Willow thickets.

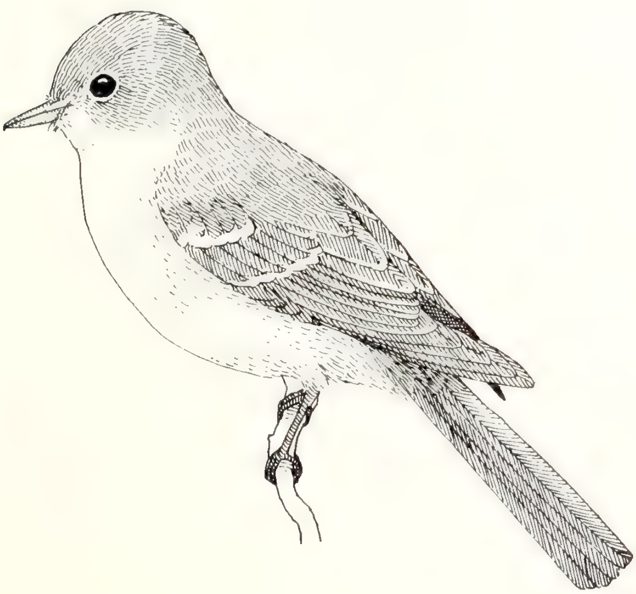
BREEDING: Breeds from late May to mid-July, with peak from mid-June to early July. Nests usually in a low crotch in a patch of willows, from ground level to 3 ft (0.9 m) up. Clutch size from 2 to 5, with mean of 3.

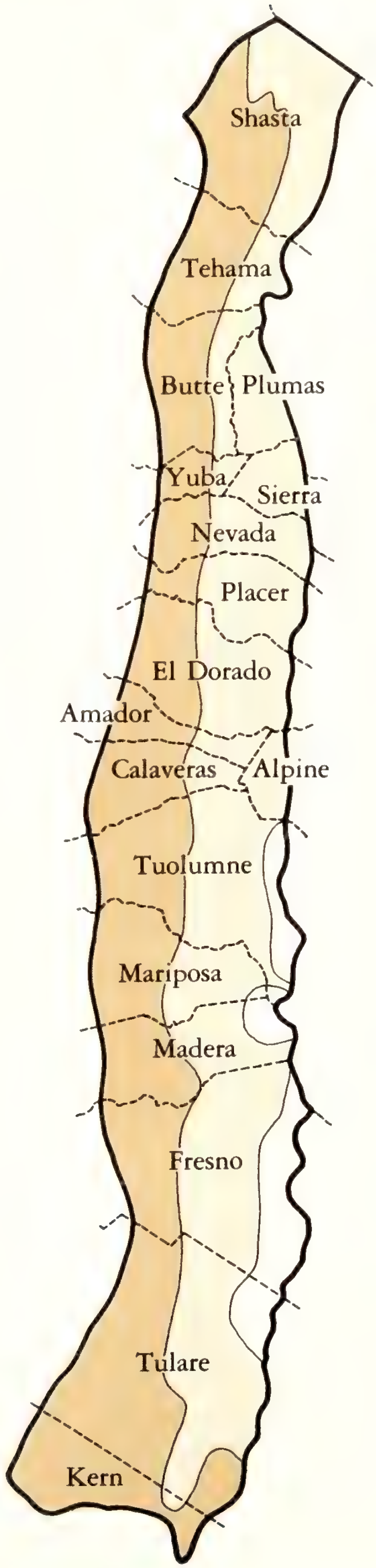
TERRITORY/HOME RANGE: No information on home range or territory size. In eastern Washington, King (1955) reported a breeding density of from 9.2 to 14 pairs per 100 acres (40 ha) in scrub habitat.

FOOD HABITS: Feeds almost entirely on flying insects, captured by hawking from exposed perches. Also gleans some insects from foliage.

OTHER:

REFERENCES: Grinnell and Storer 1924, Aldrich 1953, King 1955.





Hammond's Flycatcher

B100 *(Empidonax hammondii)*

STATUS: No official listed status. Common summer resident in the Sierra Nevada forest of middle elevations.

DISTRIBUTION/HABITAT: Widely distributed in spring and summer in forests with medium to high canopy coverage from ponderosa pine type up to lodgepole pine type. Most common in mature forests form mixed-conifer zone upward, where breeds in cool, well-shaded sites.

SPECIAL HABITAT REQUIREMENTS:

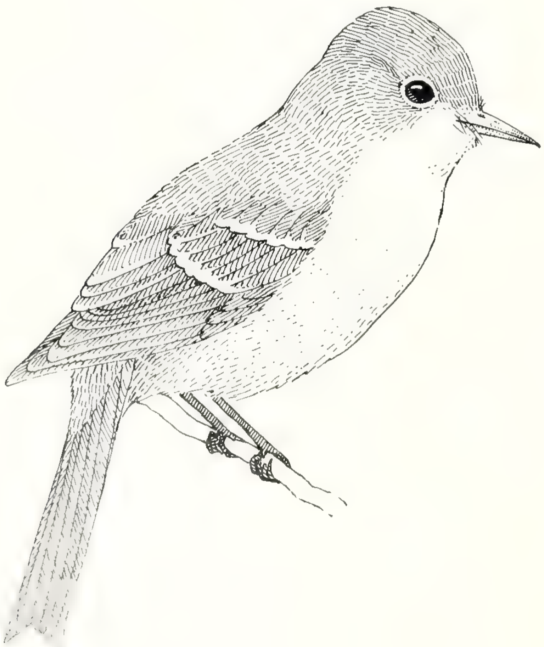
BREEDING: Breeds from mid-May to late July, with peak from mid-June to early July. Nests on horizontal limbs of deciduous or coniferous trees, from 12 to 50 ft (3.7 to 15 m) up, with average height of 25 ft (7.6 m). Clutch size from 3 to 5, with mean of 4.

TERRITORY/HOME RANGE: No data on home range size. In a Montana coniferous forest, territory size varied from 1.5 to 3.8 acres (0.6 to 1.5 ha), averaging 2.6 acres (1.1 ha) (Manuwal 1970). In Colorado aspen habitat, Beaver and Baldwin (1975) reported densities of 4.7 and 1.4 birds/25 acres (10 ha) in 1965 and 1966, respectively. In aspen-conifer habitat, densities were 2.8 birds/25 acres (10 ha) in 1965 and 1.4 birds/25 acres (10 ha) in 1966.

FOOD HABITS: Eats mainly flying insects, taken by hawking from relatively high or exposed perches.

OTHER: In the field, extremely difficult to distinguish from congener, the dusky flycatcher. Most reliable criteria for field identification are song, nesting behavior, and habitat preference (Gaines 1977). Specimen record indicates this species found up to 10,000 ft (3050 m) in the Sierra Nevada.

REFERENCES: Davis 1954; Johnson 1963, 1965; Beaver and Baldwin 1975.



Dusky Flycatcher

B101 *(Empidonax oberholseri)*

STATUS: No official listed status. Common summer resident in suitable habitat.

DISTRIBUTION/HABITAT: Widely distributed in spring and summer from chaparral zone up to lodgepole pine forests. Generally avoids forests with high percentage canopy cover, preferring shrubby sites or low to intermediate density forests with substantial shrub understory.

SPECIAL HABITAT REQUIREMENTS: Trees/shrubs.

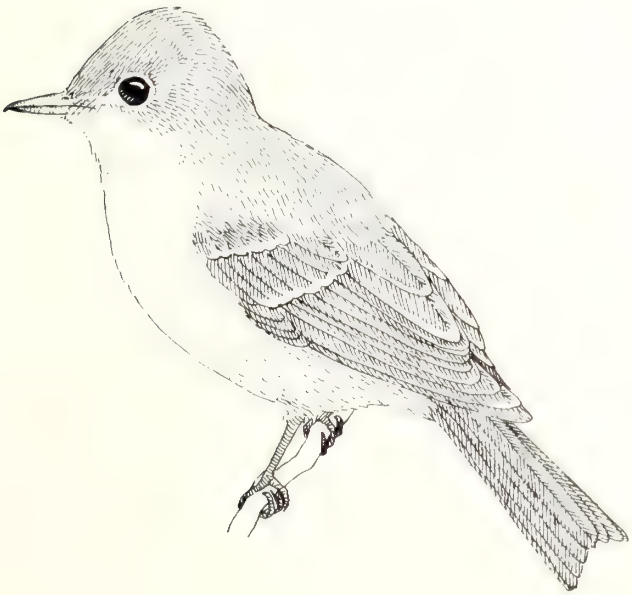
BREEDING: Breeds from early May to mid-July, with peak from mid-June to early July. Nests in low shrubs or trees in relatively dry sites. Nest usually attached to low twigs at heights from 4 to 6 ft (1.2 to 1.8 m). Clutch size 2 to 4, with mean of 3.

TERRITORY/HOME RANGE: No data on home range. In Montana, territory size in sparse coniferous forest ranged from 3.5 to 4.7 acres (1.4 to 1.9 ha), and averaged 4.0 acres (1.6 ha) (Manuwal 1970).

FOOD HABITS: Flying insects, taken aerially above brushy vegetation by hawking from low, exposed perches, comprise the diet.

OTHER: See comments on preceding page concerning field distinction between this and Hammond's flycatcher.

REFERENCES: Johnson 1963, 1966; Gaines 1977.



Western Flycatcher

B102 *(Empidonax difficilis)*

STATUS: No official listed status. Uncommon to fairly common summer resident in suitable habitat

DISTRIBUTION/HABITAT: Breeds in timbered sites from blue oak savannah upslope to ponderosa pine and black oak types; prefers sites with high percentage canopy cover, typically moist situations near streams or springs. After breeding season, moves upslope to meadow/forest edges in mixed-conifer and red fir zones.

SPECIAL HABITAT REQUIREMENTS: Stream, spring, or seep probably needed for nesting.

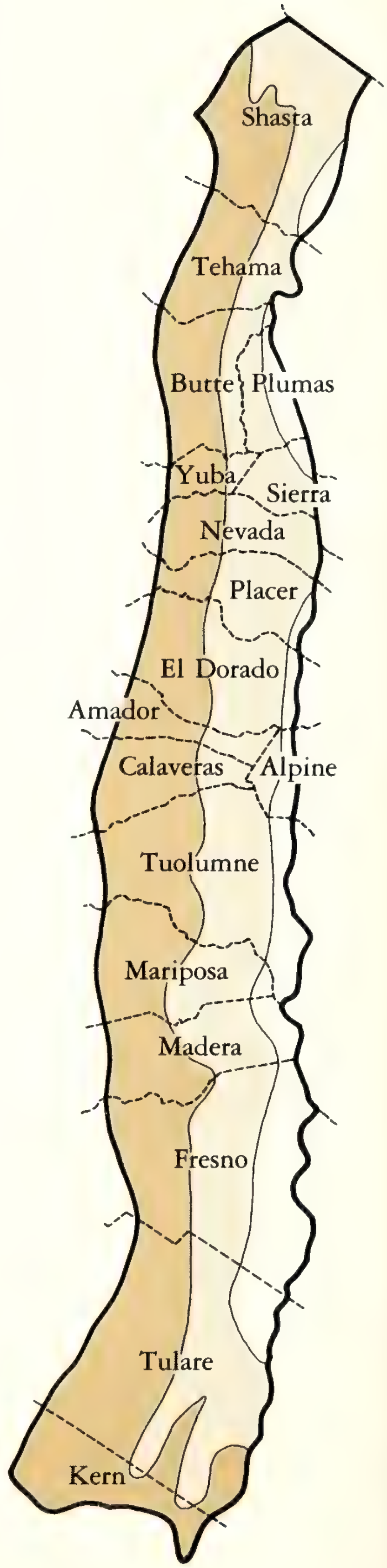
BREEDING: Breeds from early May to late July, with peak from mid-June to early July. Nest sites varied: often in crotches of large, riparian trees near water; also in old buildings and on rock ledges. Clutch size 3 to 5, with mean of 4. Sometimes double brooded.

TERRITORY/HOME RANGE: No data on territory or home range size. In Colorado in 1965 and 1966, Beaver and Baldwin (1975) reported densities of 6.9 and 1.2 birds/25 acres (10 ha) respectively.

FOOD HABITS: Flying insects, captured by hawking from perches or taken from foliage, comprise the diet.

OTHER: Although typically an inhabitant of low elevation deciduous forests, have been recorded to 10,000 ft (3050 m) in Yosemite National Park.

REFERENCES: Davis *et al.* 1963, Beaver and Baldwin 1975, Verbeek 1975.



Western Wood Pewee

B103 *(Contopus sordidulus)*

STATUS: No official listed status. Common to abundant in spring and summer.

DISTRIBUTION/HABITAT: Widespread throughout all timbered types on west slopes of the Sierra Nevada, from blue oak savannah up to lodgepole pine forests. Prefers stands with low to intermediate percentage canopy cover; more common in edge situations—around meadows, burned or cutover sites, or near streams and rivers.

SPECIAL HABITAT REQUIREMENTS:

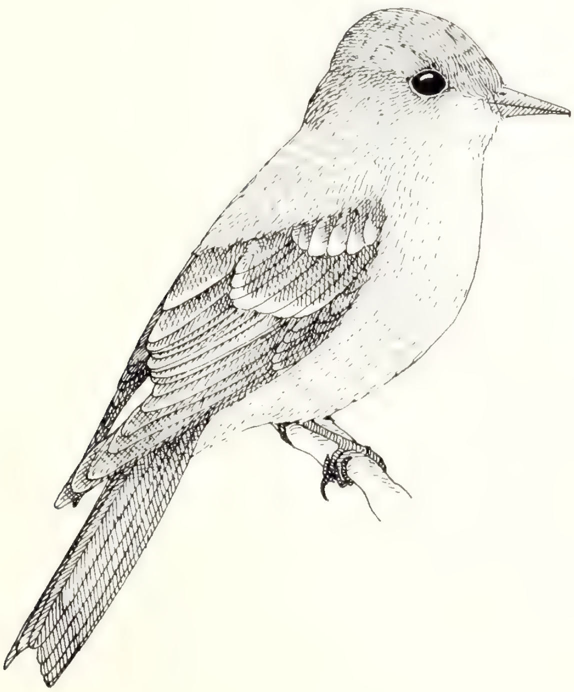
BREEDING: Breeds from early May to early August, with peak from mid-June to early July. Nests on top of horizontal branch or fork in tree of any species, from 10 to 50 ft (3.1 to 15 m) up. Clutch size from 2 to 4, with average of 3.

TERRITORY/HOME RANGE: In Colorado, Eckhardt (1976) reported territories averaged 3 acres (1.2 ha) over a 3-year period. In Colorado aspen habitat, Beaver and Baldwin (1975) reported densities of 2.5 birds/25 acres (10 ha) in 1965 and 0.3 birds/25 acres (10 ha) in 1966. No data on home range.

FOOD HABITS: Eats primarily flying insects; berries and grass seeds rarely eaten. Captures insects by hawking from prominent perch or, more rarely, by gleaning from foliage.

OTHER: Little published about ecology of species, considering abundance, conspicuousness, and wide distribution.

REFERENCES: Grinnell and Storer 1924, Beaver and Baldwin 1975.



Olive-sided Flycatcher

B104 *(Nuttallornis borealis)*

STATUS: No official listed status. Fairly common summer resident in mid-elevation coniferous forests.

DISTRIBUTION/HABITAT: Breeds in conifer forest types from ponderosa pine zone up to lodgepole pine; also breeds in black oak woodlands. Prefers stands with low percentage canopy cover. Extent and density of forest habitat seem less important than amount of air space scanned from highest perches. Most numerous where tall conifers overlook canyons or border on clearings.

SPECIAL HABITAT REQUIREMENTS: Trees/shrubs or trees/grass-forbs.

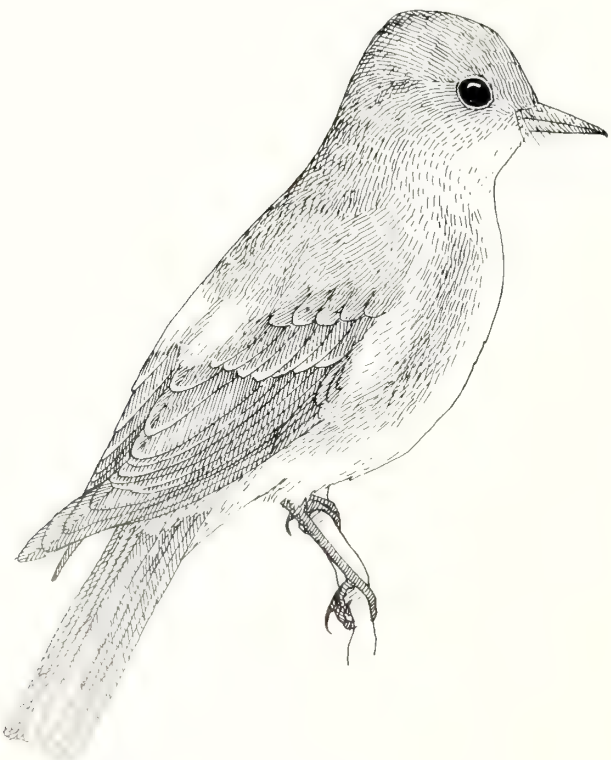
BREEDING: Breeds from mid-May to mid-July, with peak in mid-June. Nests on horizontal branches in tall conifers, ranging in height from 10 to 70 ft (3.1 to 21 m), usually from 40 to 50 ft (12 to 15 m). Clutch size from 3 to 4, with mean of about 3.

TERRITORY/HOME RANGE: No information available.

FOOD HABITS: Flying insects, hawked in midair from extremely high perches, comprise the diet.

OTHER:

REFERENCES: Tvrdik 1971, Gaines 1977.



Horned Lark

B105 *(Eremophila alpestris)*

STATUS: No official listed status. Two races found in the western Sierra Nevada. A lowland form is permanent resident, primarily from El Dorado County northward to Shasta County; second race spills over into high elevation areas from east slopes of the Sierra Nevada.

DISTRIBUTION/HABITAT: Breeds in grasslands and alpine meadows.

SPECIAL HABITAT REQUIREMENTS:

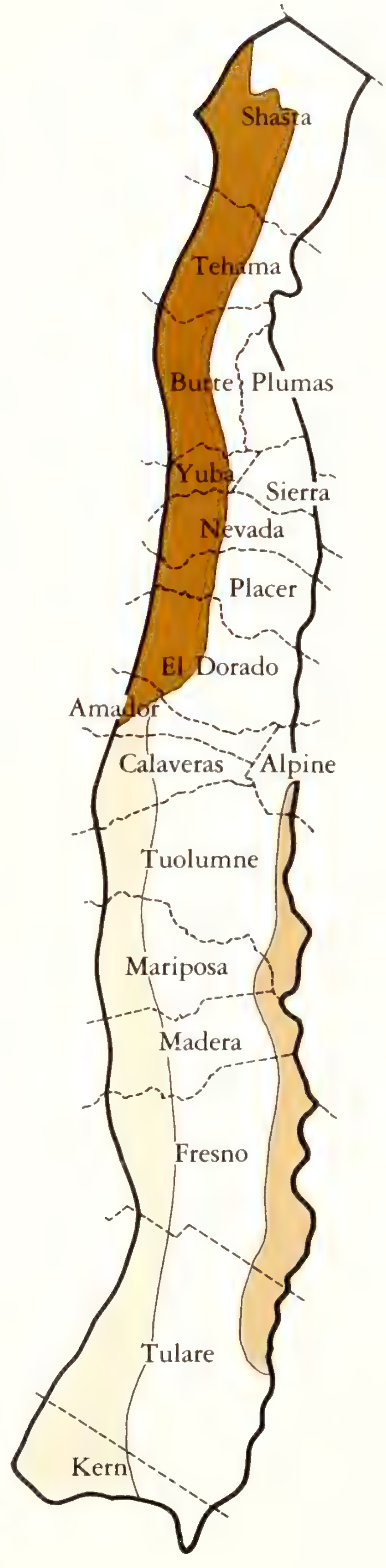
BREEDING: Breeds from early March to late July, with peak from mid-May to early July. Nests on dry ground among sparse vegetation. Clutch size from 2 to 5, with mean of 3.

TERRITORY/HOME RANGE: Breeding territories in midwestern farmlands reported as about 12 acres (4.9 ha) (Fitch 1958), ranging from 1.5 to 7.8 acres (0.6 to 3.2 ha) (Beason and Franks 1974), and ranging from 1 to 13 acres (0.4 to 5.3 ha) (Pickwell 1931). In Wyoming alpine tundra, Verbeek (1967) roughly estimated breeding territories of birds as about 4 acres (1.6 ha). No data on home range.

FOOD HABITS: Eats mostly insects, with some seeds and other vegetable matter. Takes food from the ground.

OTHER:

REFERENCES: Behle 1942, Verbeek 1967, Beason and Franks 1974.



Violet-green Swallow

B106 *(Tachycineta thalassina)*

STATUS: No official listed status. Common spring migrant and summer resident.

DISTRIBUTION/HABITAT: Breeds in all habitat types from blue oak savannahs up to lodgepole pine forests, especially at middle elevations.

SPECIAL HABITAT REQUIREMENTS: Nest cavities or crevices; medium to large openings, or open terrain.

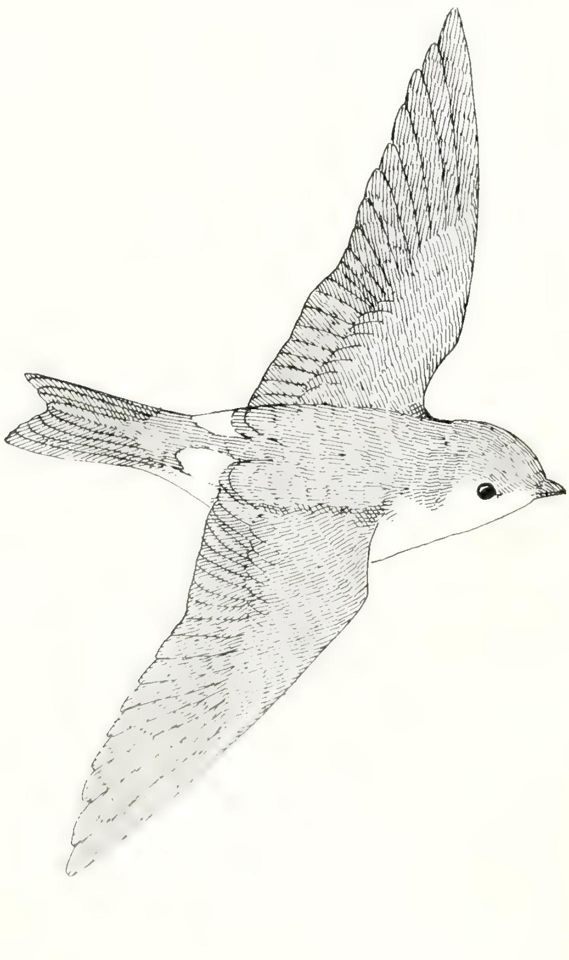
BREEDING: Breeds from late April to mid-August, with peak from late May to late July. Nests in small crevice or hole in cliff, in abandoned woodpecker hole in tree, or in hole in some human structure, generally above 5 ft (1.5 m). Clutch size from 4 to 7, usually 4 or 5.

TERRITORY/HOME RANGE: No precise data available on size of home range or territory, but Grinnell and Miller (1944) state that home range large. Presumably only immediate vicinity of nest site defended.

FOOD HABITS: Feeds on flying insects, captured in long, gliding flights above any habitat, passing through swarms of insects. Does not require bodies of water to forage over, but usually does so if such areas available.

OTHER: Solitary or weakly colonial nesters.

REFERENCES: Bent 1942, Edson 1943, Grinnell and Miller 1944, Combellack 1954.



Tree Swallow

B107 *(Iridoprocne bicolor)*

STATUS: No official listed status. Uncommon to rare spring migrant and summer resident.

DISTRIBUTION/HABITAT: Found from annual grasslands up to lodgepole pine forests. Breeds in sites with large trees; also breeds along riparian sites, around margins of ponds and lakes or in wet meadows where trees provide nest sites. Few records of nesting above 5000 ft (1520 m) in the Sierra Nevada probably exceptional.

SPECIAL HABITAT REQUIREMENTS: Nest cavities by pond, lake, stream, river, marsh, or wet meadow.

BREEDING: Breeds from mid-April to mid-August, with peak from late May to mid-July. Nests in abandoned woodpecker hole or other cavity in tree, preferably surrounded by water or on edge of water. Also uses nest boxes or cavities in buildings. No data on nest height in natural conditions. Clutch size from 3 to 7, with mean of about 5. Usually nests solitarily or in small groups.

TERRITORY/HOME RANGE: Home range is large (Kuerzi 1941, in a Connecticut study). Only nest site defended (Kuerzi 1941).

FOOD HABITS: Feeds almost exclusively on flying insects; also eats some berries and seeds. Captures insects by flying back and forth over water or at least a wet area.

OTHER: May be limited in the Sierra Nevada by availability of suitable nest sites, as has been true in other parts of the country.

REFERENCES: Kuerzi 1941, Paynter 1954, Stocek 1970.

Rough-winged Swallow

B108 *(Stelgidopteryx ruficollis)*

STATUS: No official listed status. Uncommon spring migrant and summer resident.

DISTRIBUTION/HABITAT: Breeds from annual grasslands up to ponderosa pine and black oak woodland types, expecially at lower elevations. Found in all successional stages, so long as suitable nest sites available.

SPECIAL HABITAT REQUIREMENTS: Earthen bank.

BREEDING: Breeds from early April to early August, with peak from late May to mid-July. Nests in hole in earthen bank; sometimes excavates own cavity or uses rodent's burrows, kingfisher nest sites, or natural cavities. Generally nests solitarily, unless a bank offers unusually good nest site characteristics, in which case more than one nest may be found in close proximity. Clutch size from 4 to 8, most contain 6 or 7.

TERRITORY/HOME RANGE: No data on home range. Only immediate vicinity of nest cavity defended (Lunk 1962).

FOOD HABITS: Eats flying insects, captured in long, cruising flights, generally low over water or in gullies.

OTHER: Numbers probably limited by available nest sites.

REFERENCES: Bent 1942, Grinnell and Miller 1944, Lunk 1962.

Barn Swallow

B109 *(Hirundo rustica)*

STATUS: No official listed status. Common spring migrant and summer resident.

DISTRIBUTION/HABITAT: Breeds in all habitats and successional stages from annual grasslands up to mixed-conifer forests, providing suitable nest sites available. More abundant at lower elevations.

SPECIAL HABITAT REQUIREMENTS: Cliffs, old buildings, or bridges for nesting; nearby water for mud gathering.

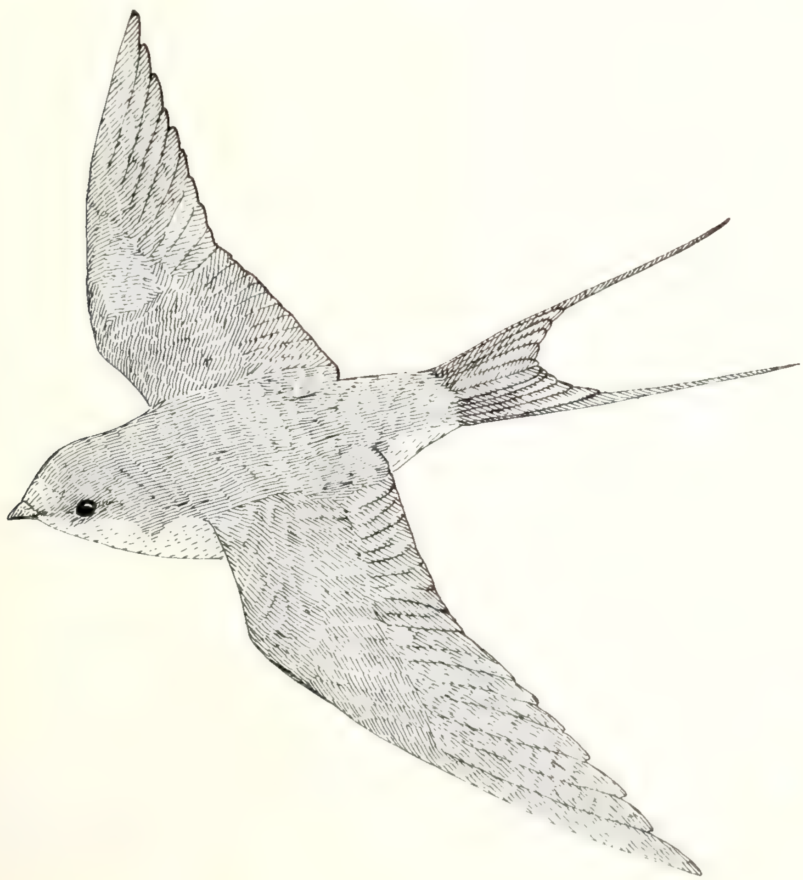
BREEDING: Breeds from early April to mid-August, with peak from mid-May to mid-July. Nests under eaves of buildings, under bridges, on rock surfaces under stream bank overhangs, or other suitably sheltered sites with solid substrate to which nest may be attached. Mud used in nest construction. Clutch size from 1 to 7, most contain 4 or 5.

TERRITORY/HOME RANGE: Data on home range scanty. Forages mostly within 4000 ft (1220 m) of the nest (Samuel 1971), or within 1300 ft (400 m) of the nest (Snapp 1976). Defends only the area immediately around nest (Davis 1937).

FOOD HABITS: Feeds on flying insects, captured in long, cruising flights, usually low over streams, ponds, or wet meadows.

OTHER:

REFERENCES: Bent 1942, Grinnell and Miller 1944, Samuel 1971, Snapp 1976.



Cliff Swallow

B110 *(Petrochelidon pyrrhonota)*

STATUS: No official listed status. Abundant spring migrant and summer resident.

DISTRIBUTION/HABITAT: Breeds from annual grasslands up into mixed-conifer forests; prefers low elevations. Occasionally known to nest at higher elevations; one colony with 30 nests located in Amador County, at 8400 ft (2560 m) elevation.

SPECIAL HABITAT REQUIREMENTS: Cliffs, old buildings, or bridges for nesting; nearby water for mud gathering.

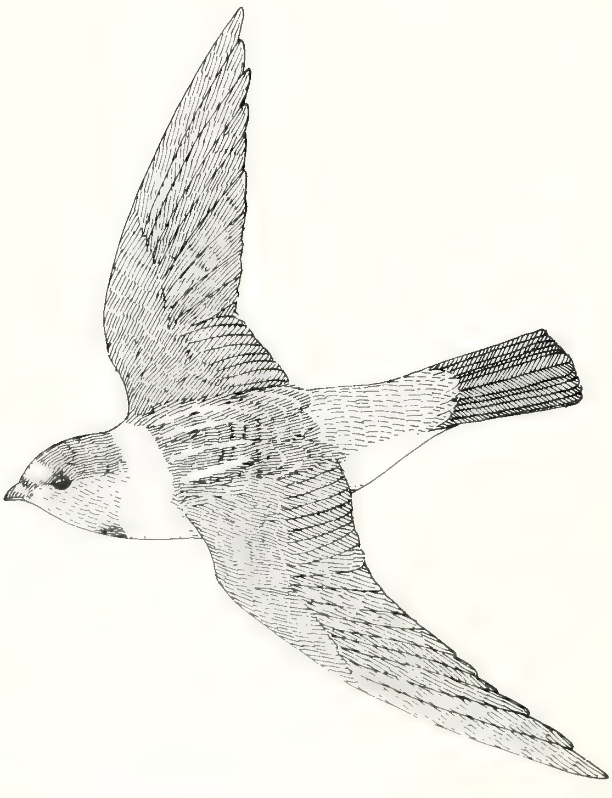
BREEDING: Breeds from mid-April to early August, with peak from early May to early July. Nest constructed of mud pellets, attached to solid, vertical surface. A funnel-shaped structure, nest has small opening directed outward from the surface to which the nest is attached. Nests often close together; species nests in colonies. Clutch size from 3 to 6, most contain 3 or 4.

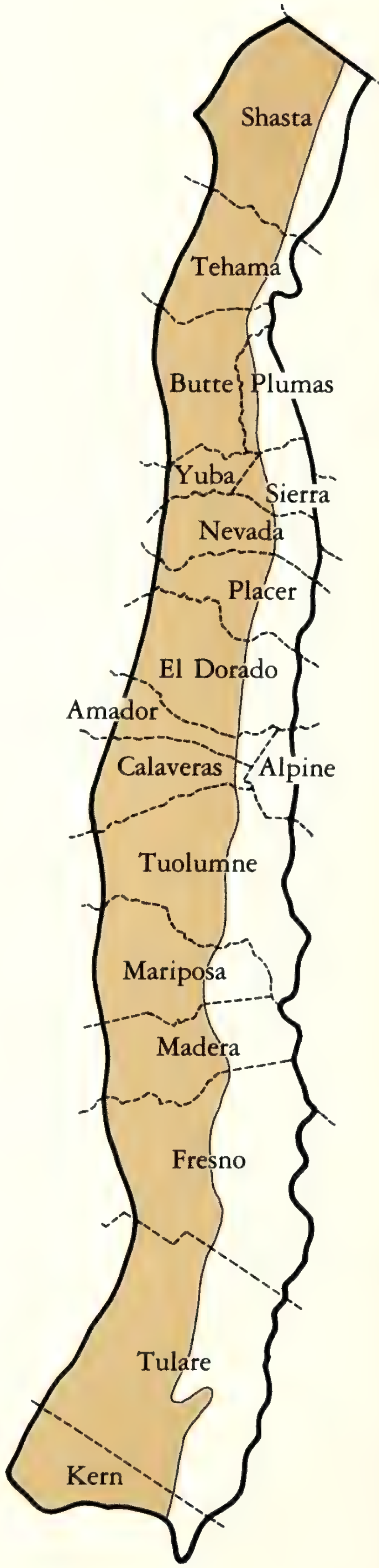
TERRITORY/HOME RANGE: In Wyoming, Emlen (1954) reported a home range of 2 to 4 mi (3.2 to 6.4 km) foraging radius around the nest. Only the area in immediate vicinity of nest defended (Emlen 1954).

FOOD HABITS: Feeds exclusively on flying insects, captured in long, cruising flight over bodies of water, grasslands, marshes, or shrubs.

OTHER:

REFERENCES: Emlen 1952, 1954; Mayhew 1958; Samuel 1971.





Steller's Jay

B111 *(Cyanocitta stelleri)*

STATUS: No official listed status. Common to abundant resident.

DISTRIBUTION/HABITAT: Breeds from ponderosa pine and black oak woodland types up to lodgepole pine forests; prefers stands of mature trees with low to intermediate percent canopy coverage. Breeding range expanded in recent years in areas of human use. Most abundant around campgrounds and picnic areas. Exhibits some upslope movement after breeding period; at least part of population regularly moves downslope in fall and winter.

SPECIAL HABITAT REQUIREMENTS:

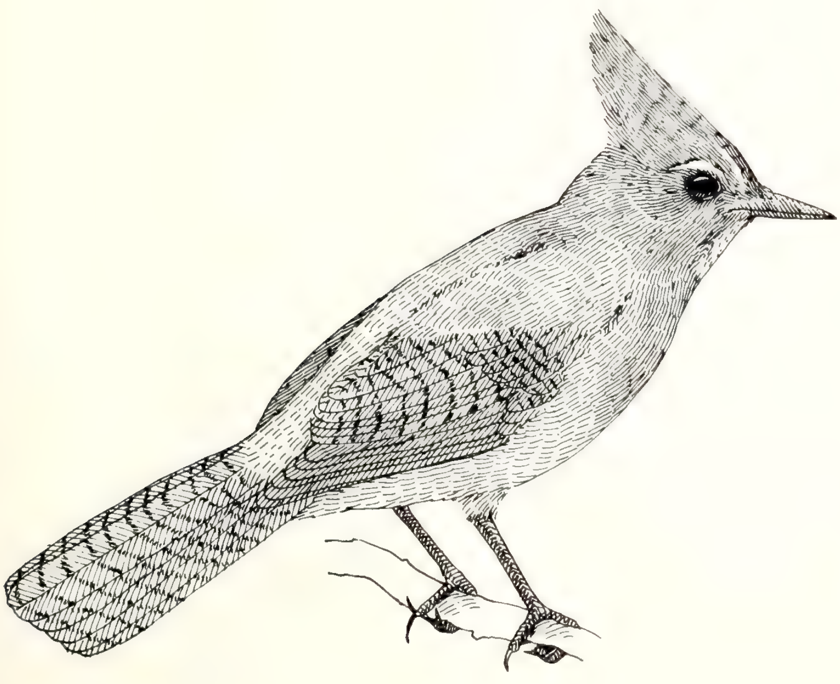
BREEDING: Breeds from early April to late July, with peak from early May to late June. Nests usually in dense foliage in young conifers, on horizontal branch near trunk. Sometimes nests in older conifers or deciduous trees. Nest height ranges from 2 to 100 ft (0.6 to 30 m); most nests between 8 and 15 ft (2.4 and 4.6 m) up. Clutch size from 3 to 5, with mode of 4.

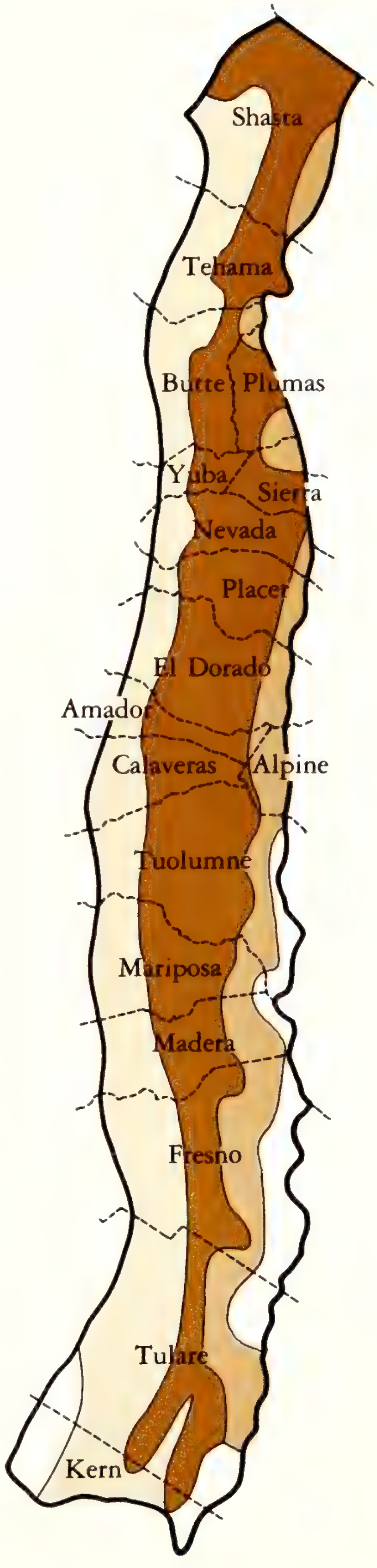
TERRITORY/HOME RANGE: No data on home range size. In Alameda County, hold year-round territories (Brown 1964), but no sizes reported.

FOOD HABITS: Omnivorous, eating mast, fruit, insects, seeds, carrion, birds' eggs and young. Uses variety of foraging techniques, including gleaning and picking. Takes food from ground and from foliage of conifers and broadleafed trees and shrubs.

OTHER: One of most secretive nesters of forest birds.

REFERENCES: Grinnell and Miller 1944, Bent 1946, Brown 1964.





Scrub Jay

B112 (*Aphelocoma coerulescens*)

STATUS: No official listed status. Common resident.

DISTRIBUTION/HABITAT: Breeds in low elevation oak and pine/oak sites, chaparral, and riparian deciduous types; prefers stands with low percent canopy coverage. Occasionally individuals wander upslope after breeding.

SPECIAL HABITAT REQUIREMENTS: Oaks or cultivated nut trees.

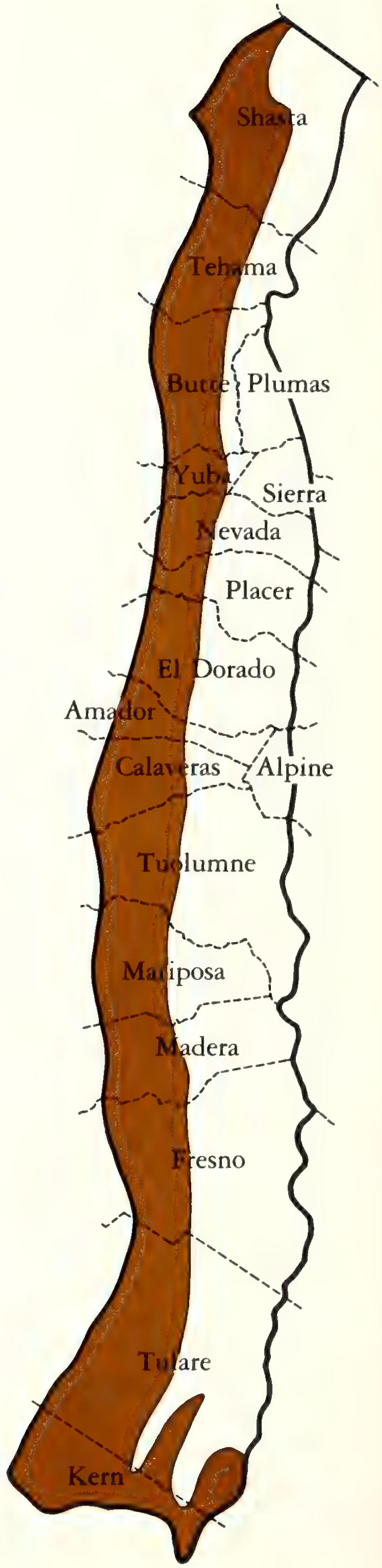
BREEDING: Breeds from early March to mid-August, with peak from late April to early July. Nests usually in low trees, vines, or shrubs, typically near water, from 3 to 50 ft (0.9 to 15 m) up. Clutch size from 2 to 7, with 4 or 5 most frequent.

TERRITORY/HOME RANGE: In Butte County, two home ranges averaged 12.7 acres (5.1 ha), and five territories averaged 5.5 acres (2.2 ha) (Ritter 1972).

FOOD HABITS: Acorns, other nuts and seeds, insects, and fruit make up majority of diet. Commonly feeds on ground near cover, gleans food from ground and litter; also digs in ground and often buries acorns and other foods for later consumption. Picks acorns and nuts from trees, and gleans foliage of trees, forbs, and grasses.

OTHER:

REFERENCES: Pitelka 1951a, Ritter 1972, Verbeek 1973.



Black-billed Magpie

B113 *(Pica pica)*

STATUS: No official listed status. Breeds east of the Sierra Nevada crest, with infrequent vagrants on west slopes.

DISTRIBUTION/HABITAT: Found uncommonly from midsummer to late winter. Feeds in clearings and areas with scattered shrubs, resting in most sites with trees. Recorded from alpine meadows downslope to mixed-conifer zone.

SPECIAL HABITAT REQUIREMENTS: Water in dry season; openings.

BREEDING: Does not breed in the western Sierra Nevada.

TERRITORY/HOME RANGE: Probably none established in the western Sierra Nevada.

FOOD HABITS: Eats primarily insects, also carrion, small mammals, and sometimes birds' eggs, fruit, and grain. Feeds on the ground, in low vegetation, and on backs of large herbivores. Searches beneath objects and gleans food from foraging surfaces.

OTHER:

REFERENCES: Linsdale 1937, Jones 1960, Erpino 1968.

Yellow-billed Magpie

B114 *(Pica nuttalli)*

STATUS: No official listed status. Permanent resident only at low elevations in the southern and central Sierra Nevada; rare vagrant at higher elevations.

DISTRIBUTION/HABITAT: Breeds in wooded stages of blue oak savannah and digger pine-oak type; prefers sites with intermediate percent canopy coverage.

SPECIAL HABITAT REQUIREMENTS: Open terrain; trees; water in dry season.

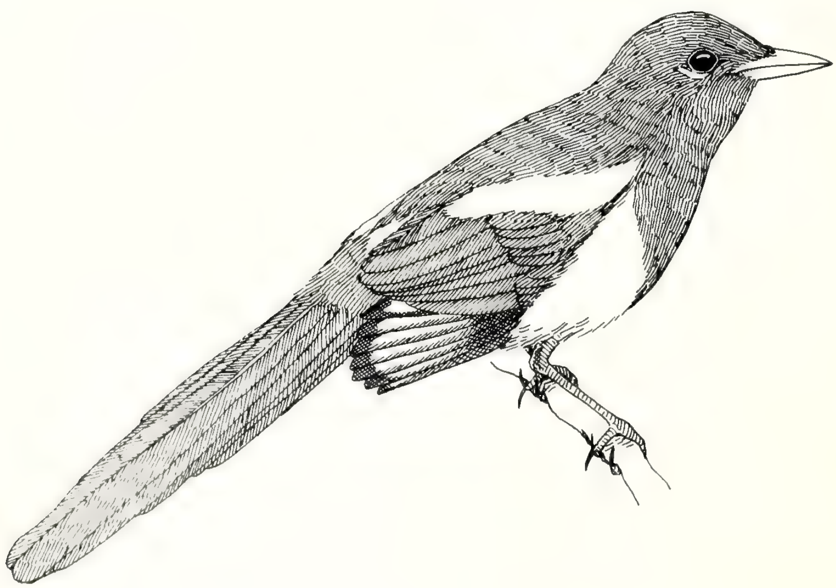
BREEDING: Breeds from late February to mid-July, with peak from early May to late June. Nests around periphery of canopy of large tree. Nests in loose colonies, usually in oaks, sycamores, cottonwoods, or digger pines. Nest height ranges from 30 to 80 ft (9.1 to 24 m), with mean of 55 ft (17 m) (Verbeek 1973). Clutch size from 5 to 8, with mean of 6.5.

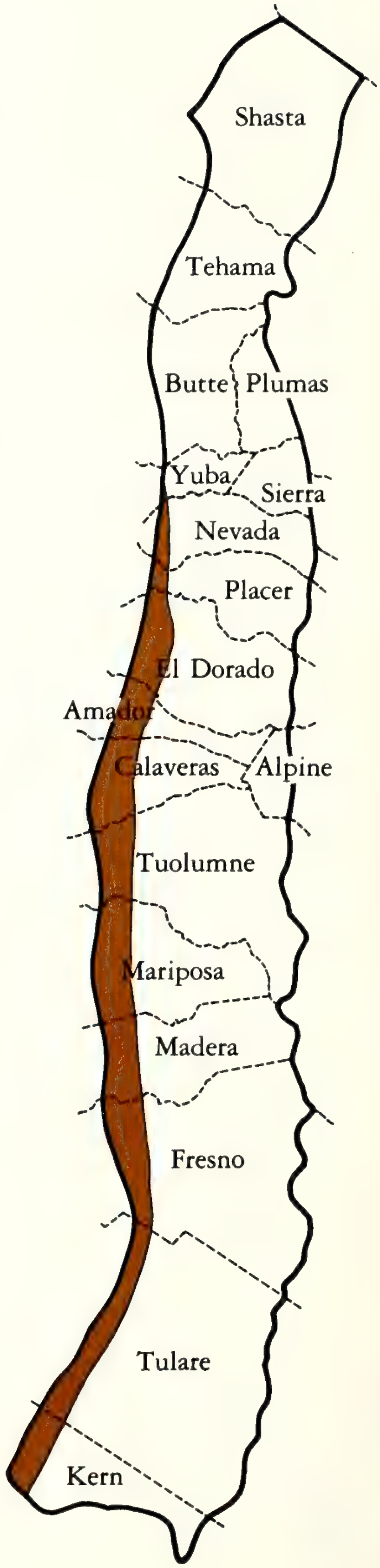
TERRITORY/HOME RANGE: In Monterey County, during breeding season, home range averaged about 100 acres (40 ha), expanding to about 1500 acres (607 ha) in nonbreeding period (Verbeek 1973). Also in Monterey County, territory size, year-round, ranged from 1.5 to 4.8 acres (0.6 to 1.9 ha) with an average of 3 acres (1.2 ha) (Verbeek 1973).

FOOD HABITS: Eats insects, soil invertebrates, carrion, a wide variety of other animal foods, acorns, fruit, and occasionally raids birds' nests. Obtains food from ground, among grasses and forbs, and in air. Gleans, searches under objects (for example, dung, wood chips), and hawks for aerial insects.

OTHER: Feeds a great deal on territory during breeding season, but moves around in large flocks in nonbreeding season. Well adapted to agricultural areas.

REFERENCES: Linsdale 1937; Bent 1946; Verbeek 1972, 1973.





Common Raven

B115 *(Corvus corax)*

STATUS: No official listed status. Uncommon resident.

DISTRIBUTION/HABITAT: Breeds in all vegetation types from the annual grasslands upslope to Jeffrey pine forests, with a preference for lower elevation areas. Feeds and rests on up to the crest of the Sierra Nevada.

SPECIAL HABITAT REQUIREMENTS: Large openings; cliffs or trees for nesting.

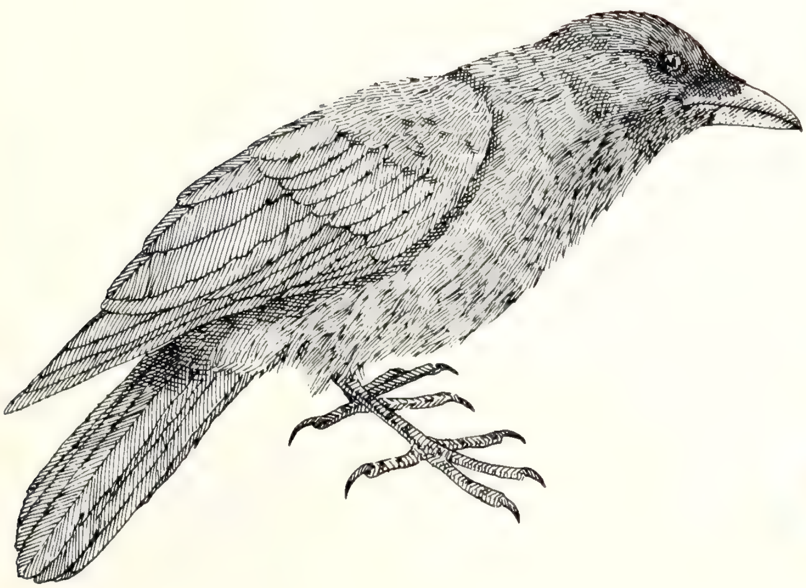
BREEDING: Breeds from mid-February to late July, with peak from mid-April to mid-June. For nesting, prefers ledge or crevice in cliff, but will use trees or manmade structures. Nest commonly sheltered by overhand or foliage. A nest tree typically the highest tree available with good cover at top. Nest height from 20 to 100 ft (6.1 to 30 m). Clutch size from 4 to 8, most contain 5 or 6.

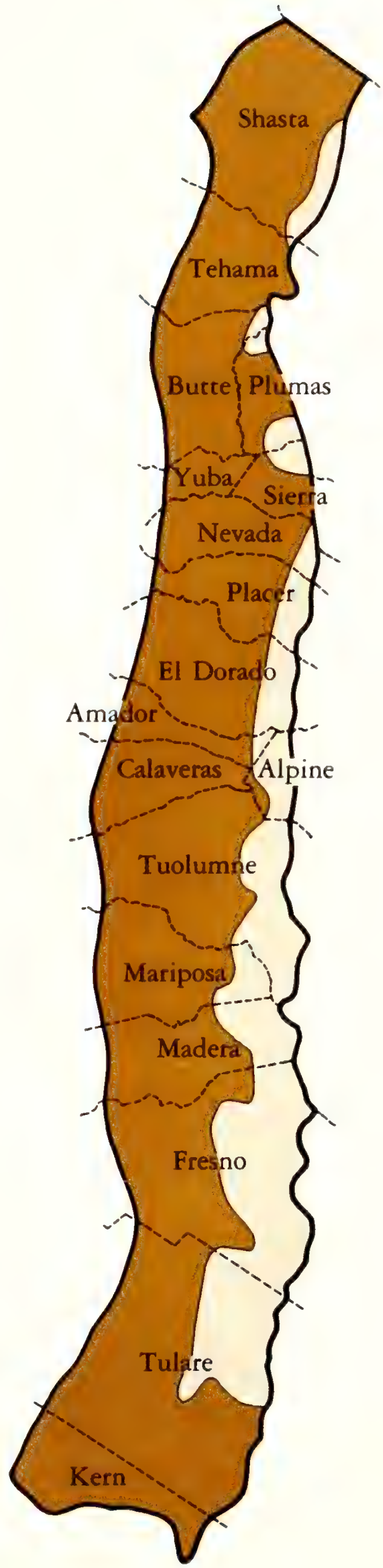
TERRITORY/HOME RANGE: No data on territory. In Wyoming, Craighead and Craighead (1956) reported two breeding home ranges of 2.6 and 4.2 mi^2 (6.7 and 10.9 km^2).

FOOD HABITS: Feeds on carrion; small, live vertebrates; and large insects. Takes food from ground and nests. Searches for food while flying and soaring.

OTHER: Generally avoids human settlements. Little known of winter distribution or breeding sites in the Sierra Nevada. May have increased range recently; has not been reported in Yosemite National Park before 1950; now listed as "uncommon" (Gaines 1977).

REFERENCES: Harlow 1922, Tyrell 1945, Bent 1946.





Common Crow

B116 *(Corvus brachyrhynchos)*

STATUS: No official listed status. Common in Central Valley; status above 1000 ft (305 m) uncertain.

DISTRIBUTION/HABITAT: A permanent resident, breeds in blue oak savannah, in digger pine-oak woodlands, and in low and mid-elevation riparian deciduous habitats. Some upslope movement as high as mixed-conifer zone in spring and fall.

SPECIAL HABITAT REQUIREMENTS: Large openings; trees for nesting.

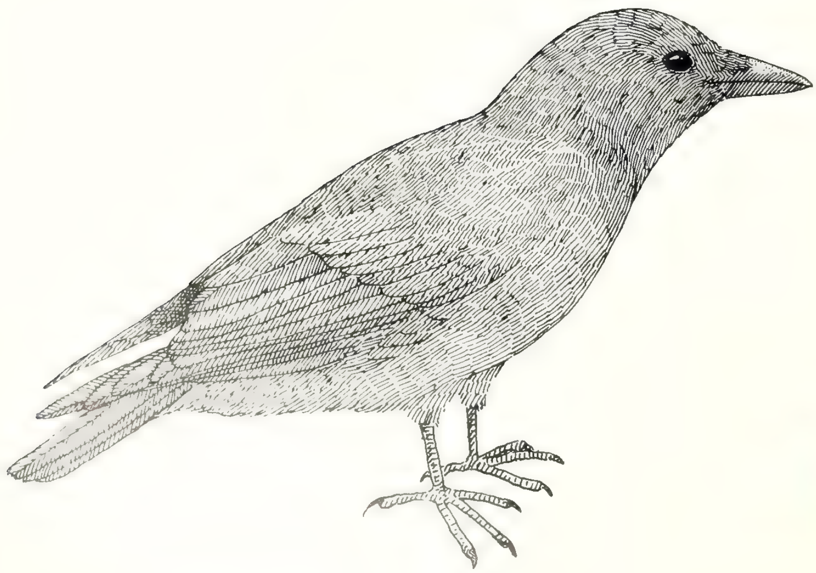
BREEDING: Breeds from late March to early July, with peak from early May to mid-June. Nests in trees, typically in crotch, from 10 to 60 ft (3.1 to 18 m) up. Clutch size from 2 to 6, with mean of 4.4.

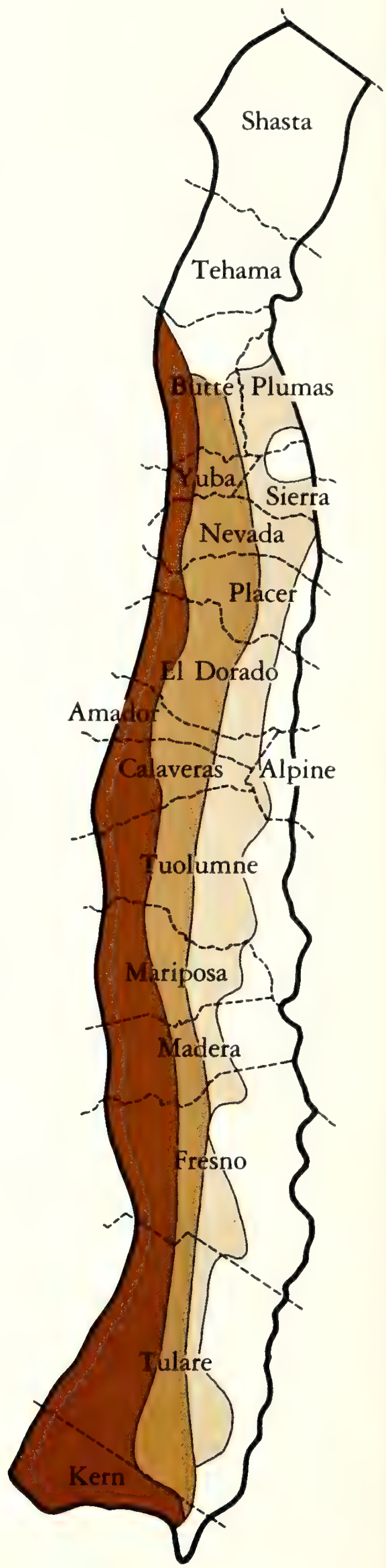
TERRITORY/HOME RANGE: No information available. Probably territorial during the breeding season (Emlen 1942). Several pairs sometimes nest in loose association.

FOOD HABITS: Eats seeds and nuts, fruits, insects, small vertebrates, carrion, and eggs. Obtains food from the ground, from vegetation, and from nests. Foraging techniques include gleaning and searching while in flight.

OTHER:

REFERENCES: Emlen 1940, 1942; Bent 1946.





Piñon Jay

B117 *(Gymnorhinus cyanocephalus)*

STATUS: No official listed status. Uncommon vagrant in late summer and fall; apparently comes to west slopes of the Sierra Nevada from east side localities.

DISTRIBUTION/HABITAT: Sporadic occurrence from Jeffrey pine forests down to blue oak savannah; prefers sites lacking high percent canopy cover.

SPECIAL HABITAT REQUIREMENTS: Openings.

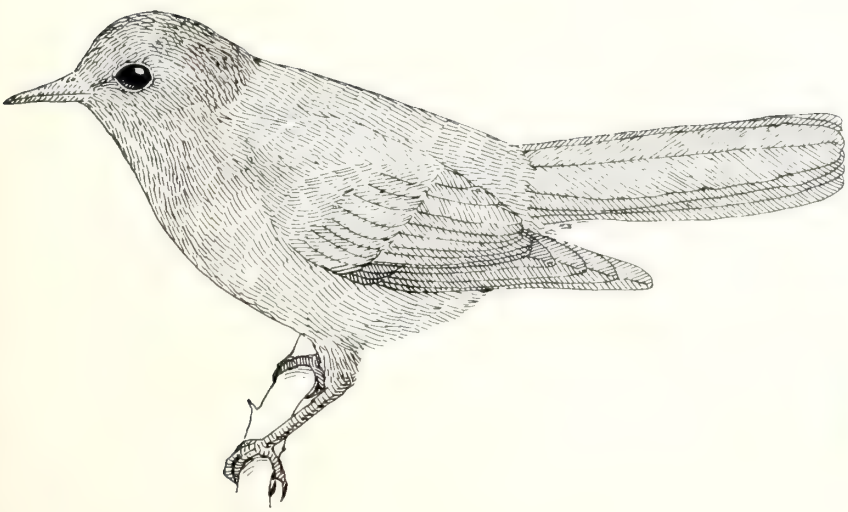
BREEDING: Does not breed in the western Sierra Nevada.

TERRITORY/HOME RANGE: One flock in New Mexico ranged over 11.2 mi^2 (29 km^2) (Ligon 1971); another in Arizona ranged over 8 mi^2 (21 km^2) (Balda and Bateman 1971).

FOOD HABITS: Pine seeds make up the majority of the diet; also eats insects, tender young pine cones, fruits, and birds' eggs and young. Feeds on the ground, on cones, foliage, and bark. Foraging techniques include gleaning, cone feeding, crevice picking, and bark flaking. Stores pine nuts.

OTHER: Flocks become nomadic when cone seed crop in home range poor. May wander hundreds of miles at such times.

REFERENCES: Balda and Bateman 1971, 1972; Balda *et al.* 1972.



Clark's Nutcracker

B118 *(Nucifraga columbiana)*

STATUS: No official listed status. Common resident; few breeding records in western Sierran zone. Probably breeds more commonly on east slope.

DISTRIBUTION/HABITAT: Breeds in variety of high altitude conifer habitats, most birds remaining above 8000 ft (2440 m) all year. Some descend to lower elevations in late summer and fall, feeding on seeds of Jeffrey, ponderosa, and sugar pines. Seldom descends below 4000 ft (1220 m). Prefers high-altitude rocky sites with sparse forest that includes pines.

SPECIAL HABITAT REQUIREMENTS: Pines.

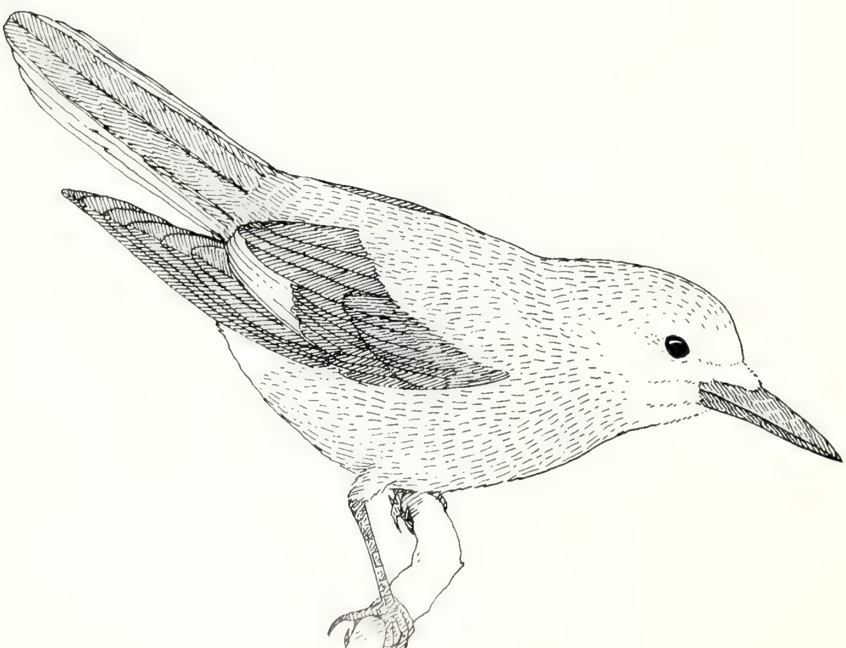
BREEDING: Breeds from late February to early August, with peak from early April to early June. Nests in a conifer, often small one, from 7 to 150 ft (2.1 to 46 m) up, though most below 50 ft (15 m). Clutch size from 2 to 6, with mode of 3.

TERRITORY/HOME RANGE: In Montana, a single breeding territory occupied 2.1 acres (0.9 ha) (Mewaldt 1956). In Mono County, Dixon (1934) reported foraging over 1.5 mi (2.4 km) from nest.

FOOD HABITS: Eats pine seeds and insects; also berries, birds' eggs and nestlings, and carrion. Obtains food from cones on trees or on ground, from foliage and bark, and from the air. Rips open cones, gleans and hawks insects.

OTHER:

REFERENCES: Dixon 1934, Mewaldt 1956, Tomback 1977.



Mountain Chickadee

B119 *(Parus gambeli)*

STATUS: No official listed status. Abundant resident.

DISTRIBUTION/HABITAT: Breeds from ponderosa pine and black oak woodland zone up through lodgepole pine forests; prefers stands with large trees and less than 70 percent canopy coverage. In fall, winter, and spring, ranges downslope into oak and pine/oak woodlands.

SPECIAL HABITAT REQUIREMENTS: Nest cavities.

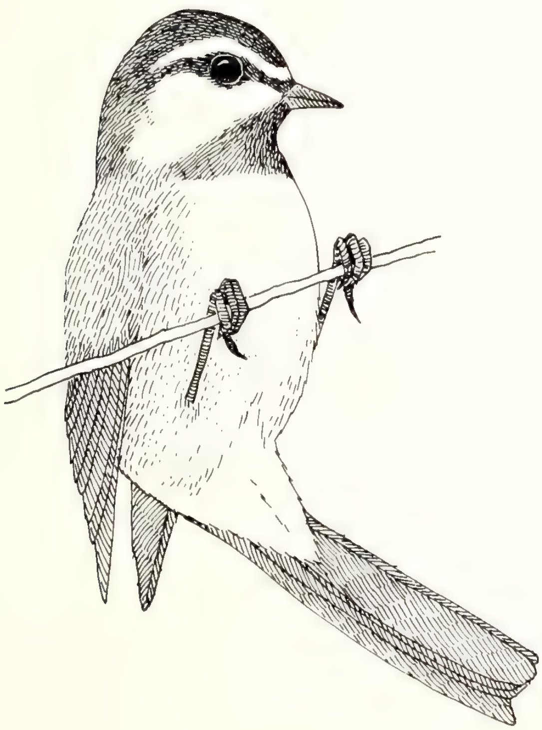
BREEDING: Breeds from early May to mid-August, with peak from late May to late July. Nests in small cavity in snag or stump, usually an abandoned woodpecker hole or, occasionally, a natural cavity. Clutch size from 5 to 9.

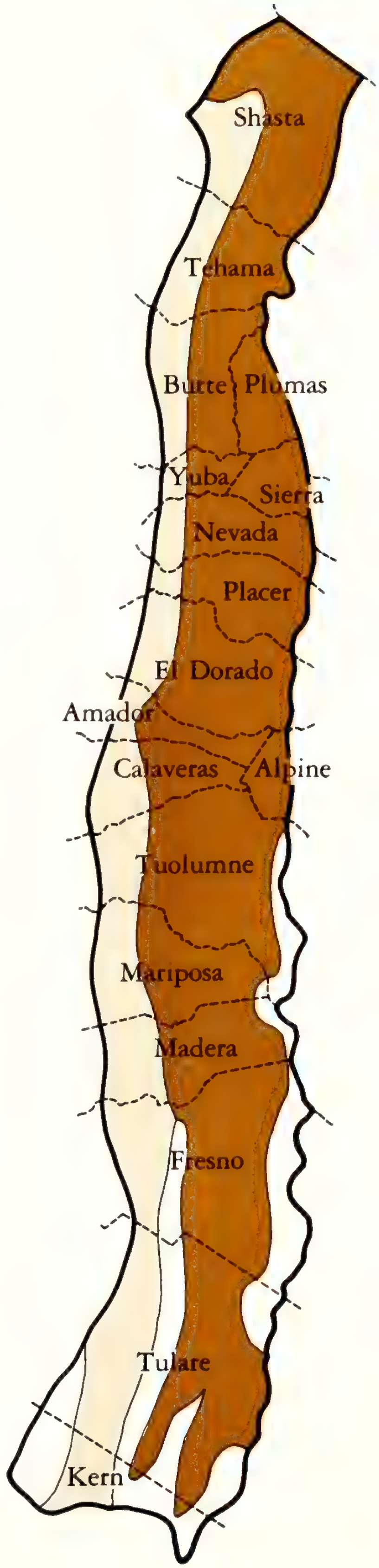
TERRITORY/HOME RANGE: In Utah, banded adults studied by Dixon and Gilbert (1964) formed winter flocks and remained in vicinity of breeding grounds; none noted to visit points more than about 0.8 mi (1.3 km) apart. In Arizona piñon-juniper-ponderosa pine ecotone, Laudenslayer and Balda (1976) indicate a mean breeding territory size of 3.7 acres (1.5 ha) while a single partial territory mapped by Minock (1971) in Utah covered at least 21 acres (8.5 ha). Discrepancy in size estimates suggests need for more field work.

FOOD HABITS: Feeds on small insects, gleaned from foliage and twigs of trees.

OTHER: Often most abundant species in winter in high elevation breeding range.

REFERENCES: Grinnell and Miller 1944, Bent 1946, Dixon and Gilbert 1964.





Chestnut-backed Chickadee

B120 *(Parus rufescens)*

STATUS: No official listed status. Rare resident from the central Sierra Nevada northward.

DISTRIBUTION/HABITAT: Range extended only recently into the Sierra Nevada; now known to occur year-round. Prefers moist forests of mixed hardwoods and conifers; may be found in other habitats. Permanent resident in ponderosa pine, black oak woodland, and mixed-conifer types.

SPECIAL HABITAT REQUIREMENTS: Nest cavities.

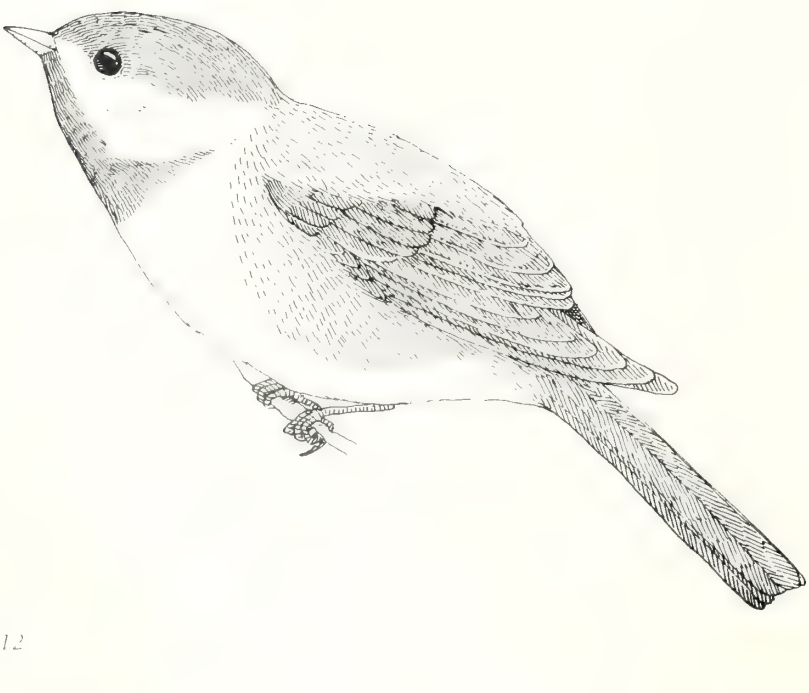
BREEDING: Breeds from late March to late July, with peak from early May to late June. Excavates own nest cavity in decaying wood in snag or stub, or uses abandoned woodpecker nest cavity. Nests usually within 10 ft (3.1 m) of ground; have been recorded as high as 80 ft (24 m). Lays from 5 to 9 eggs per clutch, usually 6 or 7.

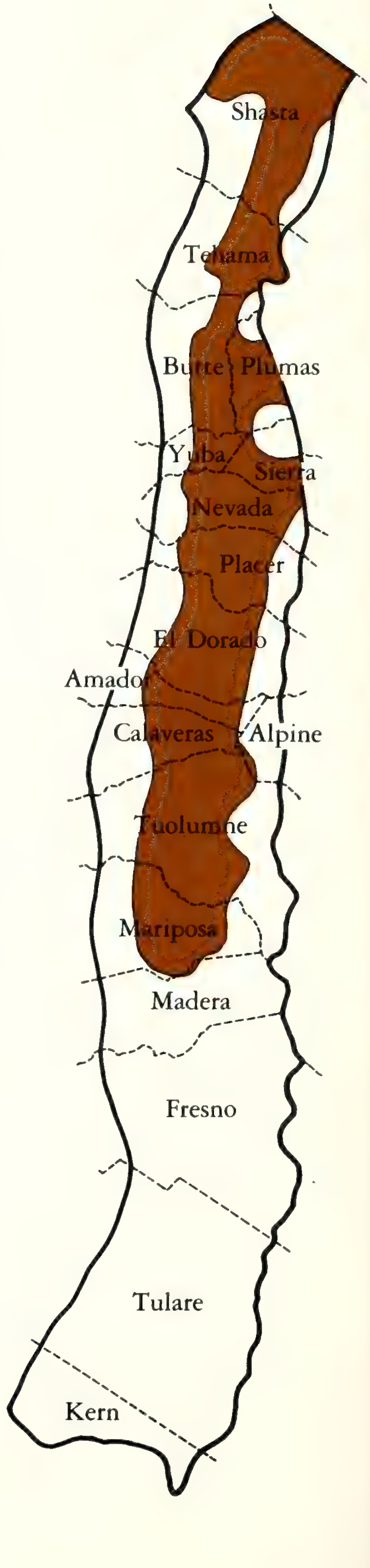
TERRITORY/HOME RANGE: No data on home range. In oak woodland in San Mateo County, Hertz *et al.* (1976) reported a mean breeding territory size of 3.3 acres (1.3 ha) (n = 2).

FOOD HABITS: Eats primarily small insects, also takes conifer seeds and fruits. Gleans food from outer foliage and twigs, preferably of conifers. Usually hovers while gleaning food.

OTHER:

REFERENCES: Sturman 1968a, 1968b; Crase 1976.





Plain Titmouse

B121 *(Parus inornatus)*

STATUS: Breeds in wooded sites from blue oak savannah up to ponderosa pine and black oak woodland types. Prefers stands with intermediate to high percentage canopy coverage and with blue live, and valley oaks.

DISTRIBUTION/HABITAT:

SPECIAL HABITAT REQUIREMENTS: Oaks; nest cavities.

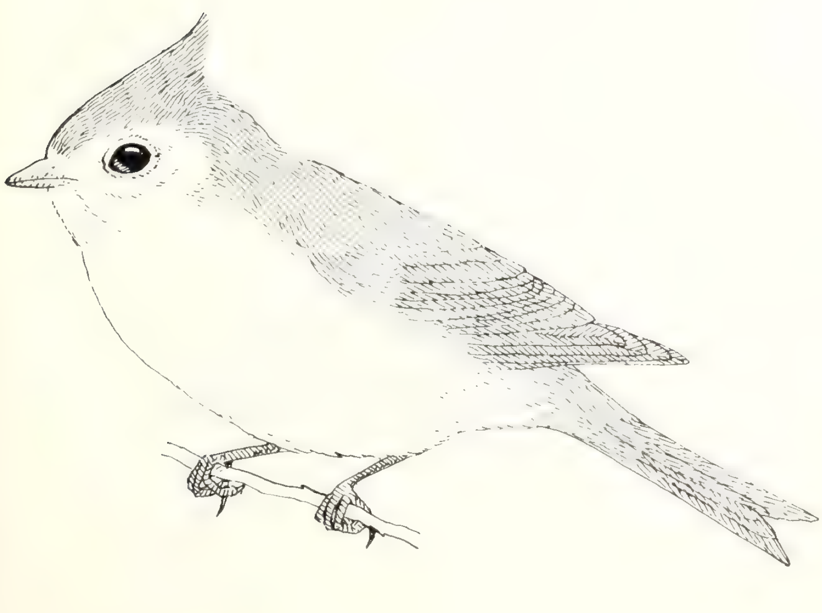
BREEDING: Breeds from mid-March to late July, with peak from early April to early June. Nests in natural cavity or old woodpecker hole; often partially excavates own cavity. Readily accepts nest boxes. Nest height ranges from 3 to 32 ft (0.9 to 9.8 m). From 3 to 9 eggs per clutch, with mode of 7.

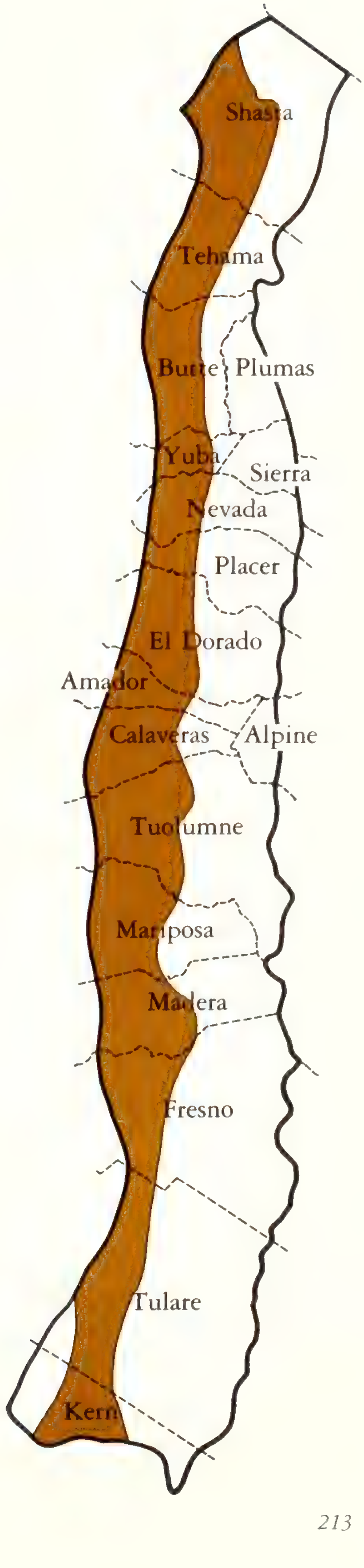
TERRITORY/HOME RANGE: Home range the same as territory. Adults permanently paired and defend territory year-round (Dixon 1949, 1956). In Alameda County, territory size ranged from 3.3 to 12.5 acres (1.3 to 5.1 ha), with mean of 6.3 acres (2.6 ha) (Dixon 1949); in another study in Alameda County live oak woodland, Dixon (1954) reported mean territory size of 5.7 acres (2.3 ha). In San Mateo County, Hertz *et al.* (1976) reported mean breeding territory size of 2.0 acres (0.8 ha) (n = 3) in oak woodlands. In Arizona, Laudenslayer and Balda (1976) found mean territory size of 3.0 acres (1.2 ha) in piñon-juniper-ponderosa pine ecotone.

FOOD HABITS: Eats small insects, fruits, and seeds. Gleans food mostly from tree foliage, twigs, and branches, also from the herb/grass layer. Sometimes pulls off bark and pries open galls, flowers, lichens, and others.

OTHER:

REFERENCES: Dixon 1949, 1954, 1956; Hertz *et al.* 1976.





Bushtit

B122 *(Psaltriparus minimus)*

STATUS: No official listed status. Common resident.

DISTRIBUTION/HABITAT: Breeds in blue oak savannahs and digger pine-oak woodlands; prefers stands of low percent canopy coverage. Also breeds in intermediate to high density chaparral stands. After breeding season, moves upslope in fairly large numbers into ponderosa pine and black oak types, remaining until early fall.

SPECIAL HABITAT REQUIREMENTS: Oaks; trees/shrubs.

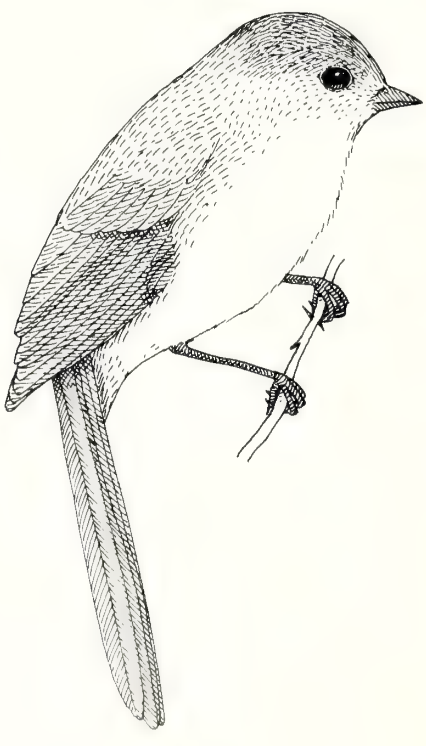
BREEDING: Breeds from mid-February to early August, with peak from early April to early June. Nest has shape of long bag or pouch suspended from branch of tree or shrub, often not concealed by foliage. Nest height ranges from 4 to 50 ft (1.2 to 15 m); most nests within 15 ft (4.6 m) of ground. Clutch contains from 4 to 7, with mode of 6.

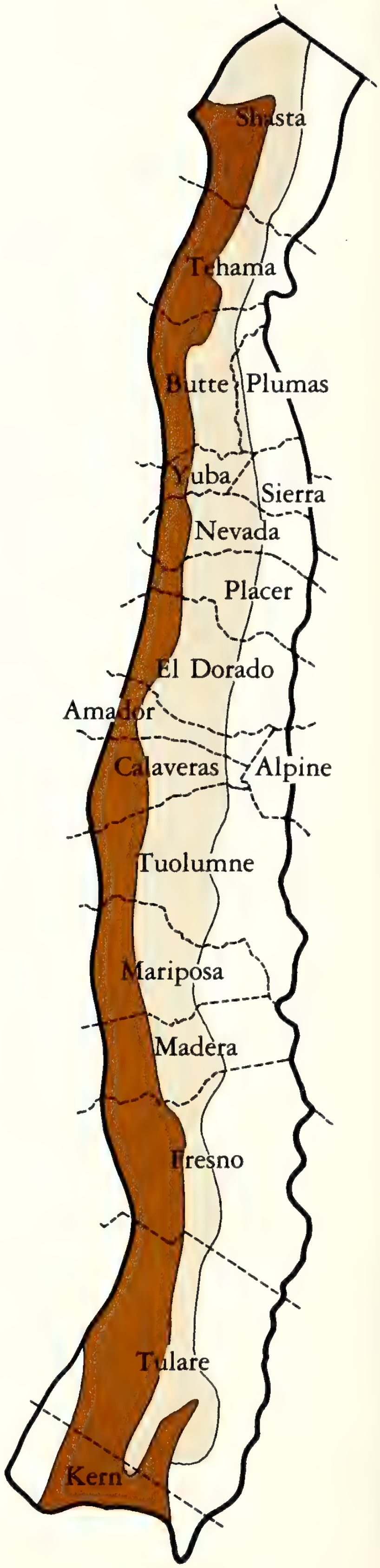
TERRITORY/HOME RANGE: In Santa Barbara County, Ervin (1974) shows maps of winter home ranges, but sizes not given. In a northern Arizona piñon-juniper-ponderosa pine ecotone, Laudenslayer and Balda (1976) reported an average territory size of about 3.5 acres (1.4 ha). In San Mateo County, Hertz *et al.* (1976) reported breeding territory sizes in oak woodland ranging from 0.7 to 1.3 acres (0.3 to 0.5 ha) with mean of 1.0 acre (0.4 ha) (n = 12).

FOOD HABITS: Feeds mainly on small insects; takes some seeds and even nectar. Gleans food from foliage and twigs of trees and shrubs. Forages in flocks from late summer until breeding season.

OTHER:

REFERENCES: Grinnell and Miller 1944, Bent 1946, Ervin 1974.





White-breasted Nuthatch

B123 *(Sitta carolinensis)*

STATUS: No official listed status. A common permanent resident in suitable habitat.

DISTRIBUTION/HABITAT: Prefers large oaks or other large-limbed, rough-barked species, especially ponderosa or Jeffrey pine, particularly with low to intermediate canopy cover, as breeding habitats. Also nests in conifer forests from ponderosa pine up to lodgepole pine type, again with preference for low to intermediate crown cover, and for stands with larger trees at higher elevations. No evidence of altitudinal migration.

SPECIAL HABITAT REQUIREMENTS: Nest cavities.

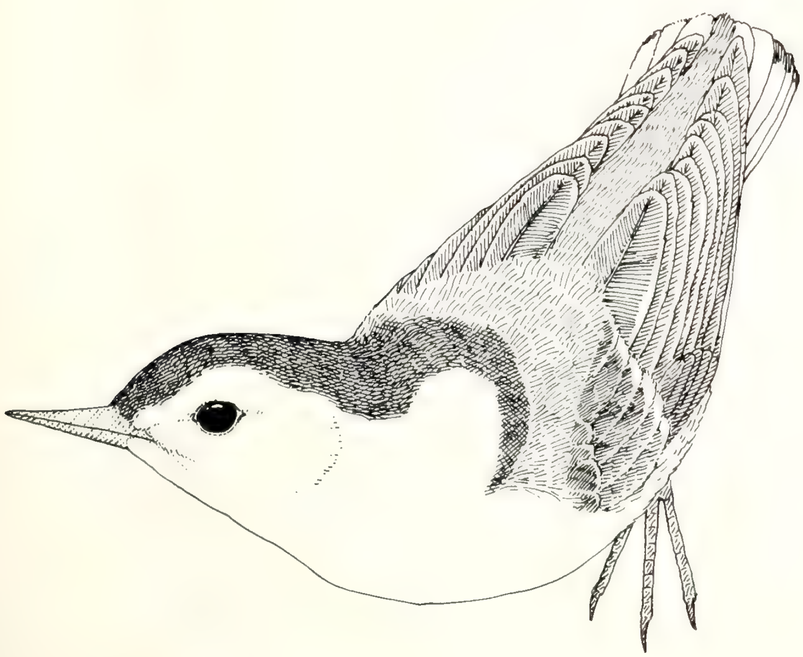
BREEDING: Breeds from mid-March to early August, with peak from early May to late June. Clutch size from 5 to 9, with mean of 7.5. Nests in natural cavity or woodpecker hole in dead or partly dead tree.

TERRITORY/HOME RANGE: In New Hampshire, Kilham (1972) reported that territories approximate 37 acres (15 ha), while in Colorado, Hering (1948) noted feeding territories of two breeding pairs of 1.7 and 2.3 acres (0.7 and 0.9 ha). In Kansas, Fitch (1958) reported home range of one bird as 37 acres (15 ha).

FOOD HABITS: Insects comprise the major food source during breeding season; at other times insects, acorns, and large seeds eaten. Gleans insects from bark of live and dead tree trunks and branches. Stores acorns and seeds for winter; food caches defended.

OTHER: Suffers when large conifers logged. Little field study done in recent decades.

REFERENCES: Kilham 1972.



Red-breasted Nuthatch

B124 *(Sitta canadensis)*

STATUS: No official listed status; abundant permanent resident in suitable habitat.

DISTRIBUTION/HABITAT: Widely distributed in conifer forest types from ponderosa pine belt up to lodgepole forests; prefers breeding in areas with at least pole-sized trees and tight-foliaged types, such as firs. Some downslope migration in fall; may be found in fall, winter, and spring as low as blue oak savannahs.

SPECIAL HABITAT REQUIREMENTS: Snags or nest cavities.

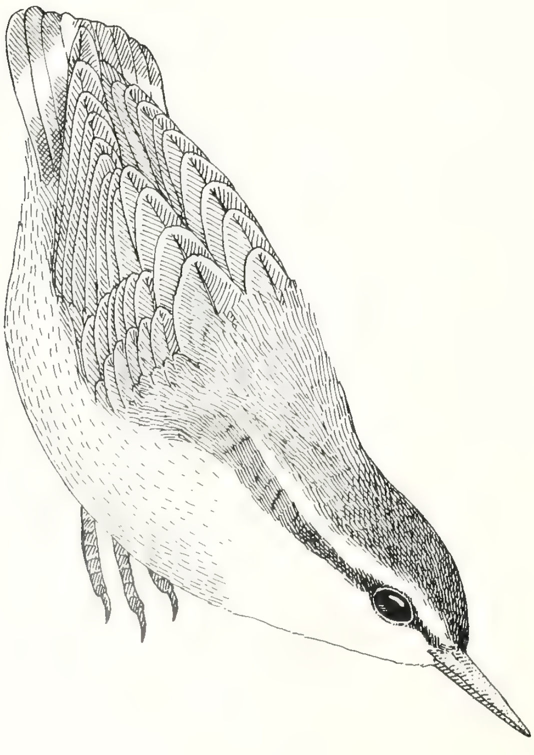
BREEDING: Breeds from late April to early August, with peak activity from early June to late July. Clutch size from 4 to 7, usually contains 5 or 6. Excavates own nest cavity, less often uses old woodpecker hole, from 2 to 120 ft (0.6 to 37 m) above ground, in dead tree or rotton stub on living tree. Pitch smeared at the nest opening.

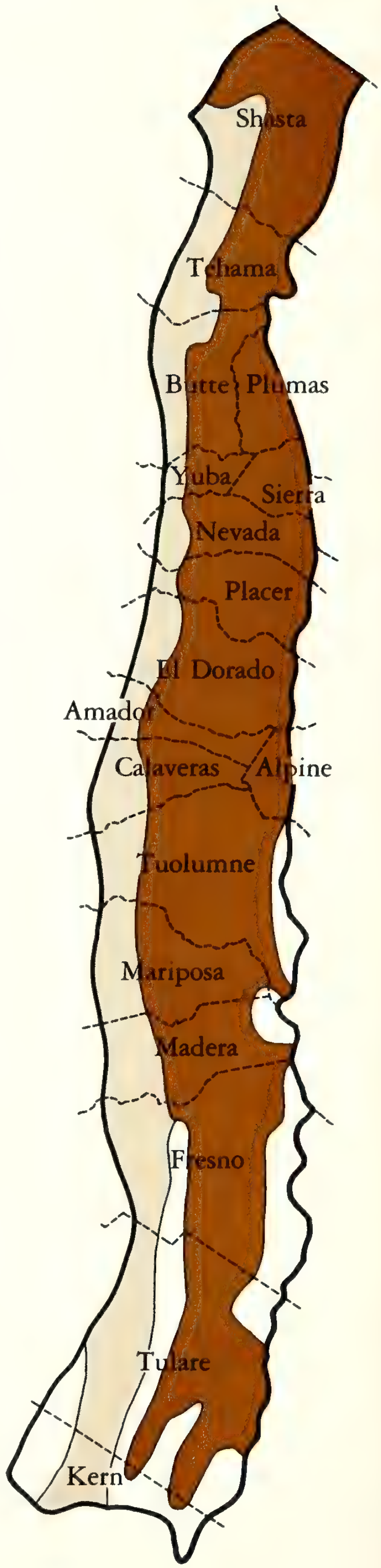
TERRITORY/HOME RANGE: No information.

FOOD HABITS: Gleans insects from trunk and branches of trees, rarely from foliage. Also probes for insects in bark crevices. Eats conifer seeds in significant amounts.

OTHER:

REFERENCES: Kilham 1973.





Pygmy Nuthatch

B125 *(Sitta pygmaea)*

STATUS: No official listed status. Locally common permanent resident; may be somewhat erratic in occurrence.

DISTRIBUTION/HABITAT: More common in southern than in northern Sierra Nevada; confined to ponderosa pine, mixed-conifer, and Jeffrey pine forests with mature trees and less than 70 percent canopy coverage.

SPECIAL HABITAT REQUIREMENTS: Pines; snags or nest cavities.

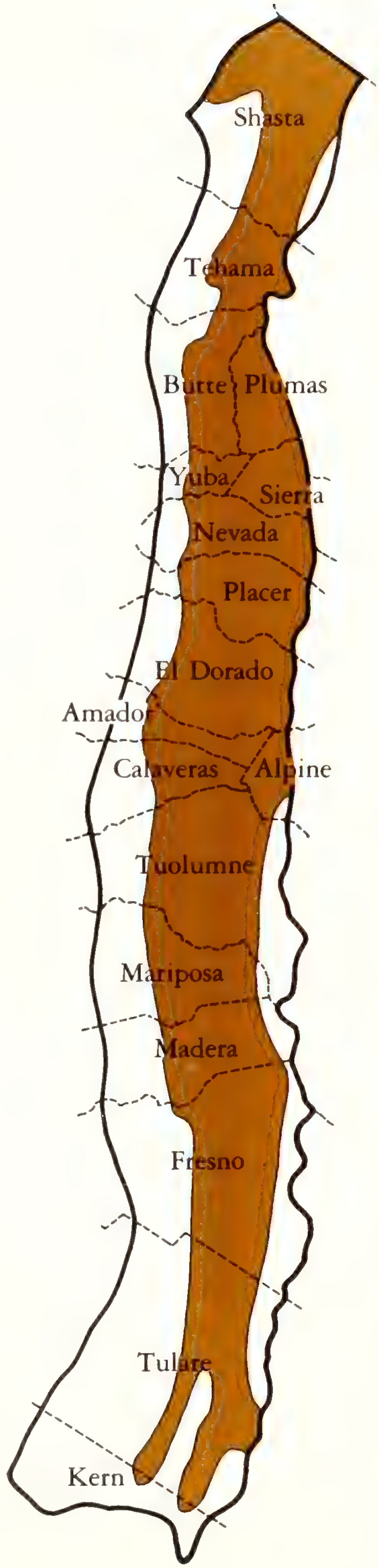
BREEDING: Breeds from late April to mid-August, with peak between mid-June and late July. From 5 to 9 eggs (mean of 7) laid in cavity nest in dead, decayed tree trunk or stub. Excavates nest cavity or uses old cavity, from 10 to 50 ft (3.1 to 15 m) above ground (usually above 20 ft [6.1 m]).

TERRITORY/HOME RANGE: Territorial during the breeding period; apparently not during winter. No information available on home range, if different from territory. In a Marin County coastal pine forest, territory size ranged from 1.9 to 3.3 acres (0.8 to 1.3 ha) and averaged 2.7 acres (1.1 ha) (Norris 1958).

FOOD HABITS: Insectivorous in the breeding season, expands diet in nonbreeding period to include pine seeds. Food gleaned from terminal needle clusters, cones, and new shoots of pines, usually high in trees.

OTHER: Roosts in tree cavities, often communally, as many as 150 birds reported in one cavity (Knorr 1957); apparently a heat conservation adaptation practiced during cold periods.

REFERENCES: Norris 1958, Bock 1969.



Brown Creeper

B126 (*Certhia familiaris*)

STATUS: No official listed status. Common permanent resident in suitable habitat; more often heard than seen.

DISTRIBUTION/HABITAT: Found in all conifer types in the breeding season; prefers mature stands with at least 70 percent canopy coverage. In nonbreeding periods may be found at lower elevations, into blue oak savannahs.

SPECIAL HABITAT REQUIREMENTS:

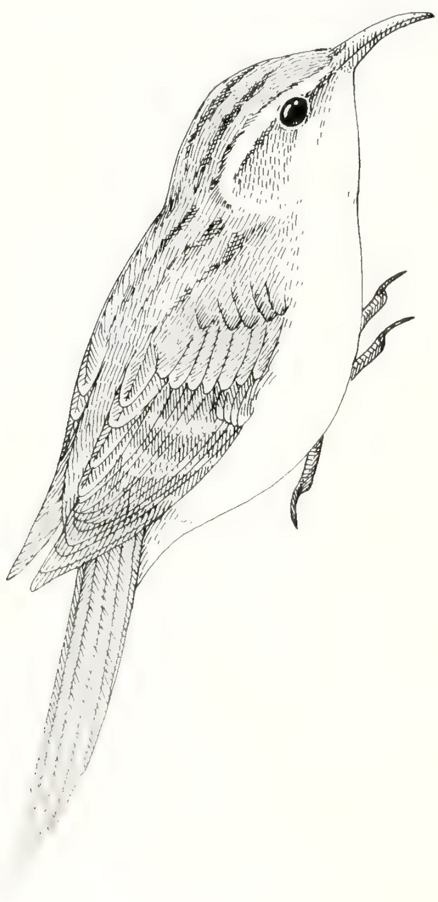
BREEDING: Breeds from early April to mid-August, with peak activity from mid-June to mid-July. Clutch size from 4 to 8, most contain 5 or 6. Nests from 3 to 15 ft. (0.9 to 4.6 m) up, behind loose strips of bark on tree trunks. Prefers incense-cedar for nest sites, but uses other conifers in the western Sierra Nevada.

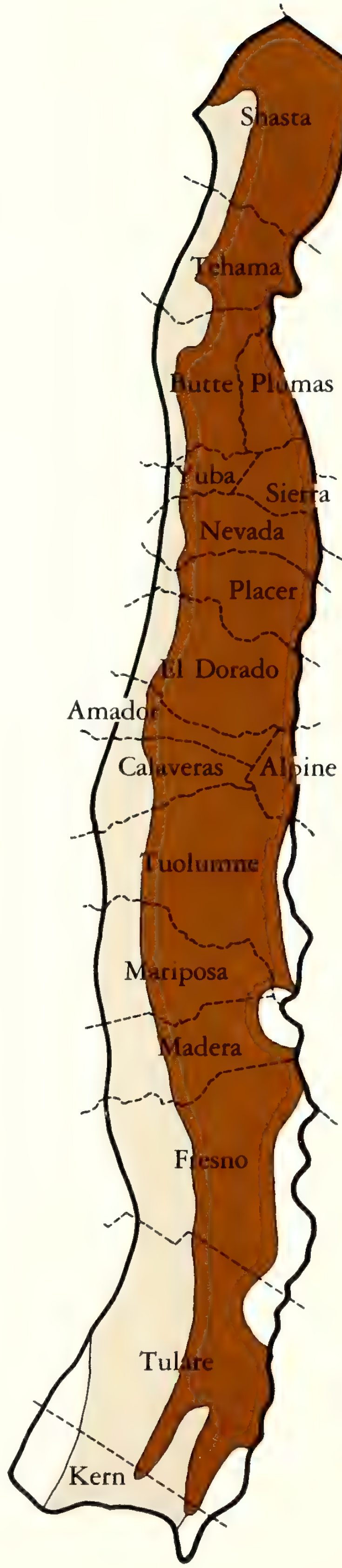
TERRITORY/HOME RANGE: No information.

FOOD HABITS: Exclusively insectivorous; gleans food from bark surface and probes bark crevices on tree trunks and large branches.

OTHER: No detailed life history available.

REFERENCES: Bent 1948.





Wrentit

B127 *(Chamaea fasciata)*

STATUS: No official listed status. Common permanent resident in suitable habitat.

DISTRIBUTION/HABITAT: A common chaparral species, breeds also in other habitat types with suitably dense stands of shrubs, up to ponderosa pine and black oak types. Adults sedentary; immatures may move upslope in late summer.

SPECIAL HABITAT REQUIREMENTS: Dense shrubs.

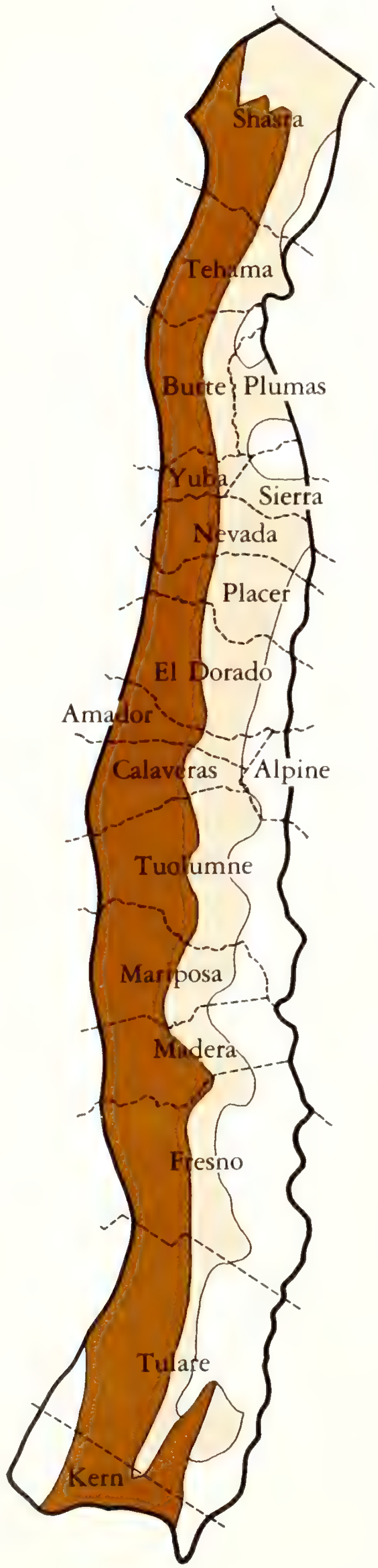
BREEDING: Breeds from late March to mid-September, with peak from late May to early July. Clutch size from 3 to 5, most contain 4. Nests well concealed within shrubbery, usually 1 to 4 ft (0.3 to 1.2 m) above ground, though sometimes as high as 7 ft (2.1 m).

TERRITORY/HOME RANGE: In Alameda County, territory and home range the same, averaging 0.8 acre (0.32 ha), with a range from 0.5 to 2.7 acres (0.2 to 1.1 ha), based on a study of 40 territories where defended year-round (Erickson 1938). In Los Angeles County, Cogswell (1962) found territory size to average 1.3 acres (0.5 ha), with a range of 0.5 to 3.0 acres (0.2 to 1.2 ha), based on 361 breeding territories.

FOOD HABITS: Eats primarily insects, spiders, and small fruits. Gleans from bark of twigs, from leaf surfaces, and from fruiting stems.

OTHER:

REFERENCES: Erickson 1938, Cogswell 1962.



Dipper

B128 (*Cinclus mexicanus*)

STATUS: No official listed status. Fairly common permanent resident in suitable habitats.

DISTRIBUTION/HABITAT: Almost totally confined to flowing, rocky streams and rivers, but occasionally forages along alpine lakeshores. Some move downslope as streams freeze in winter. Recorded at all elevations in the western Sierra Nevada up to 11,600 ft (3540 m).

SPECIAL HABITAT REQUIREMENTS: Clear, permanent streams or rivers.

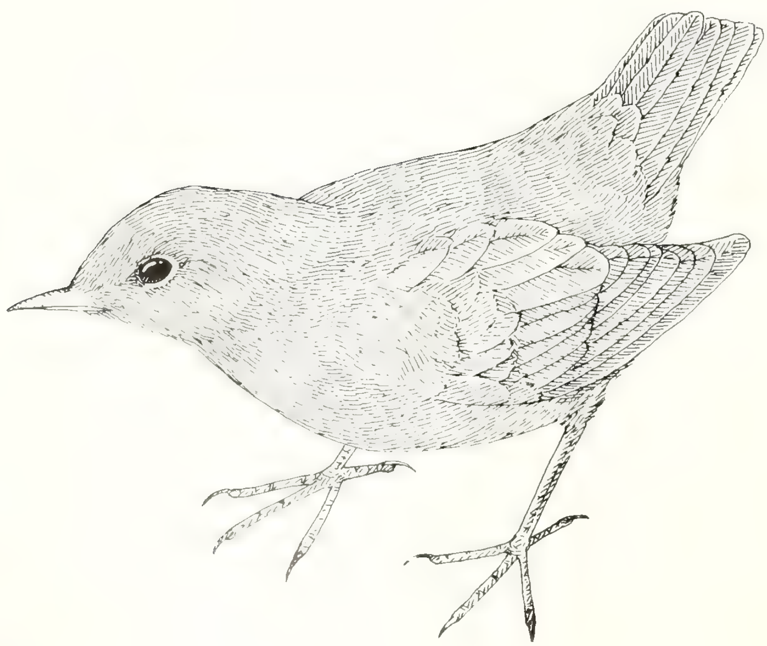
BREEDING: Breeds from early March to early August, with peak from early June to mid-July. Clutch size from 3 to 6; most contain 4 or 5. Nests in recess or on ledge, usually within 3 to 6 ft (1 to 2 m) of stream surface, on inaccessible rock wall, log, or other structure, such as a bridge.

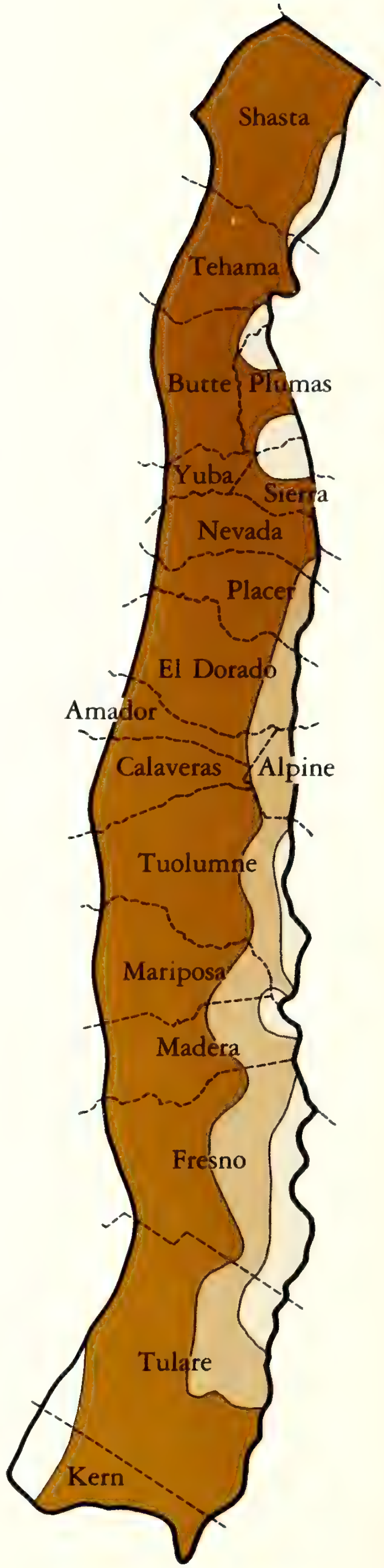
TERRITORY/HOME RANGE: Defends certain length of stream, up to 1050 ft (320 m) in length in breeding season, and from 150 to 2700 ft (46 to 820 m) during nonbreeding period, based on a Montana study (Bakus 1959b). Territory and home range the same.

FOOD HABITS: Eats mainly aquatic insect larvae and adults, snails, and fish fry. Takes directly from water or gleans from rock surfaces under water. Captures some insects in the air by hawking.

OTHER: Stream diversion projects especially detrimental to species.

REFERENCES: Hann 1950; Bakus 1959a, 1959b; Thut 1970.





Winter Wren

B129 *(Troglodytes troglodytes)*

STATUS: No official listed status. Uncommon permanent resident in suitable habitat; some upslope movement in fall.

DISTRIBUTION/HABITAT: Breeds usually near a stream in mature, relatively dense and well-shaded stands of ponderosa pine and mixed conifer, as well as in mid-elevation, deciduous riparian habitat. In fall, moves up into fairly dense stands of Jeffrey pine, red fir, and lodgepole pine; does not remain there over winter.

SPECIAL HABITAT REQUIREMENTS: Litter, logs in dense tangles; natural cavities.

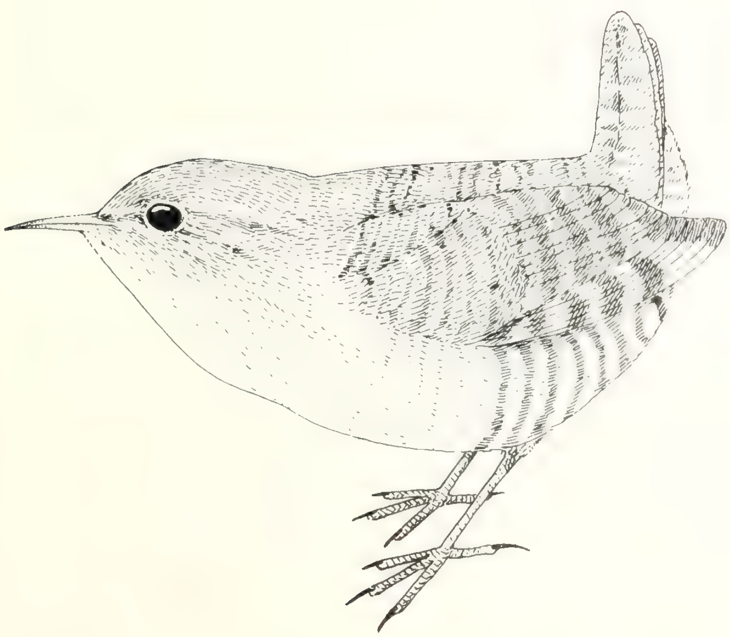
BREEDING: Breeds from early March to late August, with peak from mid-May to late July. May rear two broods per season. Clutch size from 4 to 7, usually 5 or 6. Nests in natural recess or cavity in or under log or in root tangle.

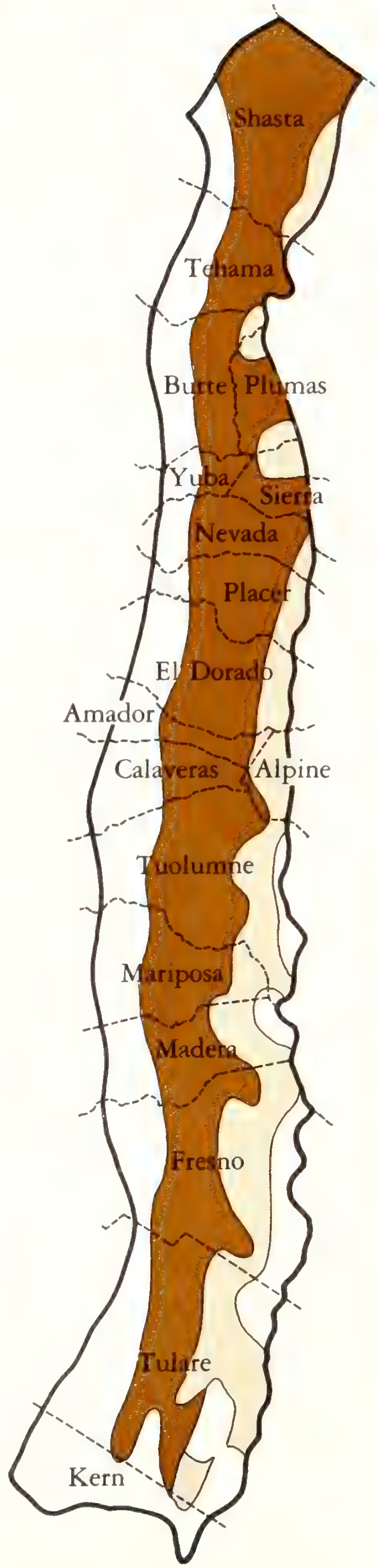
TERRITORY/HOME RANGE: Territory and home range the same, ranging year-round from 0.75 to 3.0 acres (0.3 to 1.2 ha), with average around 1.75 acres (0.7 ha), based on a study in Holland (Armstrong 1955).

FOOD HABITS: Gleans larval and adult insects from ground or near ground in tangled vegetation or downed wood.

OTHER: North American forms not studied well in the field. Uncommon and inconspicuous in the western Sierra Nevada, and distribution not well defined. More common in fall and winter than during breeding season.

REFERENCES: Armstrong 1955.





House Wren

B130 *(Troglodytes aedon)*

STATUS: No official listed status. Fairly common summer visitor at lower elevations, moving upslope in late summer, apparently after breeding.

DISTRIBUTION/HABITAT: Nests in all successional stages except grass/forb and dense forest canopies from blue oak savannah up to ponderosa pine forests and black oak woodlands. Prefers areas with low percentage canopy coverage; generally requires trees. Often found at edges of forests, woodlands, or meadows. In late summer may be found in wet meadows and willow thickets almost up to timberline.

SPECIAL HABITAT REQUIREMENTS: Nest cavities; trees/shrubs.

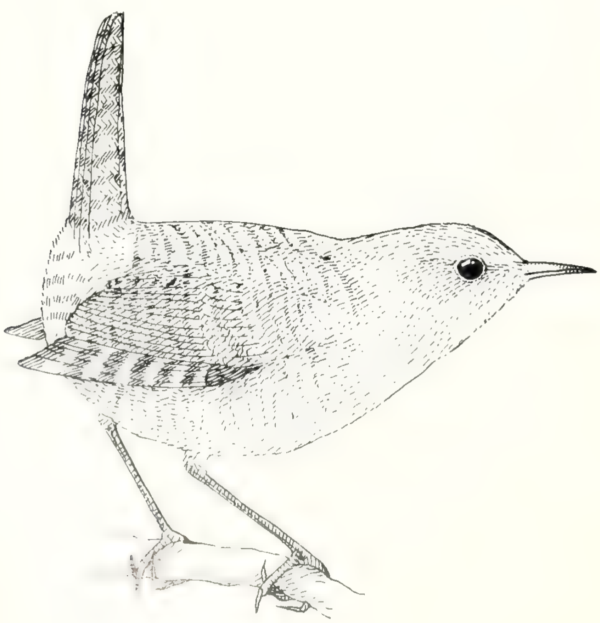
BREEDING: Breeds from early April to mid-August, with peak from late May to early July. Usually produces two broods per season. Clutch size from 3 to 9, with 5 or 6 most common. Nests in natural cavity or woodpecker hole in tree, or hole in building. Nests usually within 10 ft (3.1 m) of ground; may be as high as 30 ft (9.1 m).

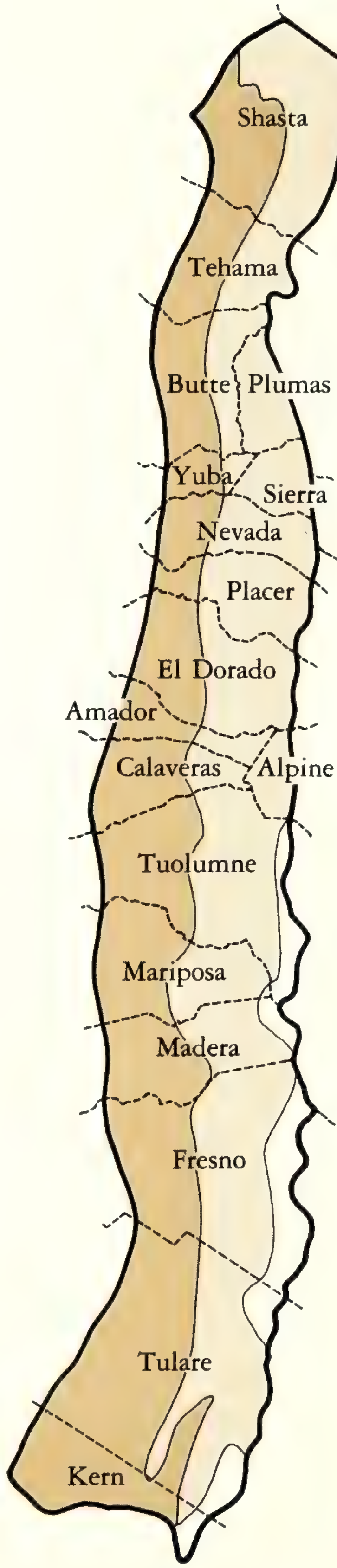
TERRITORY/HOME RANGE: No information on home range size. In Oregon, territory size averaged 2.3 acres (0.9 ha), with range of 1.1 to 4.4 acres (0.5 to 1.8 ha) in 14 breeding territories (Kroodsma 1973). In Ohio, 178 breeding territories averaged 1.0 acre (0.4 ha), with range from 0.08 to 3.6 acres (0.03 to 1.5 ha) (Kendeigh 1941b).

FOOD HABITS: Gleans insects from foliage and litter within and beneath shrubs.

OTHER: Males typcially fill unused nest cavities in territories with sticks.

REFERENCES: Kendeigh 1941b, Kroodsma 1973.





Bewick's Wren

B131 *(Thryomanes bewickii)*

STATUS: No official listed status; on the 1978 Audubon Society Blue List; apparently not declining in the western Sierran zone. A common permanent resident in suitable habitat.

DISTRIBUTION/HABITAT: Breeds in shrub and tree stages from blue oak savannah up to ponderosa pine and black oak types; prefers areas with low percent canopy coverage. Also nests in riparian deciduous habitats up to about 5000 ft (1520 m). Some occasionally move upslope in late summer.

SPECIAL HABITAT REQUIREMENTS: Natural tree cavity or rock crevice for nesting; trees/shrubs.

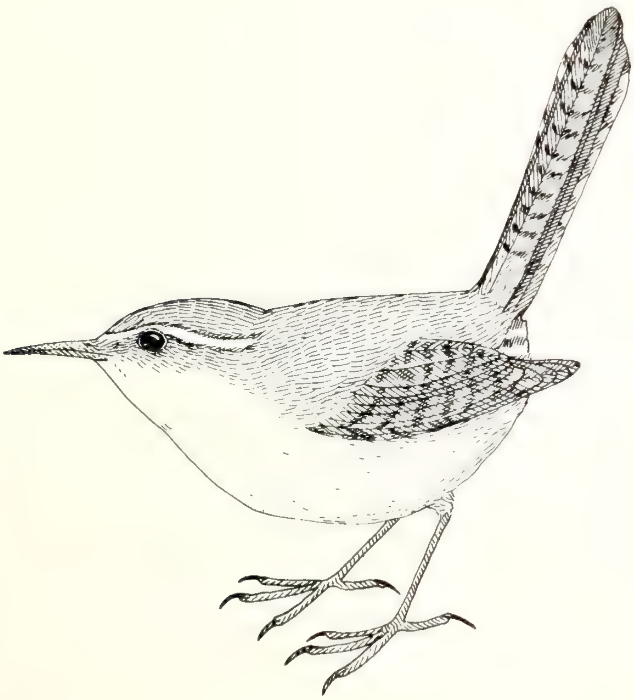
BREEDING: Breeds from mid-Feburary to early August, with peak from mid-May to late June. Clutch size from 4 to 11, most contain 7. Nests in cavities in ground or within a meter or so above it, in dead trees, rock crevices, manmade structures, and other places.

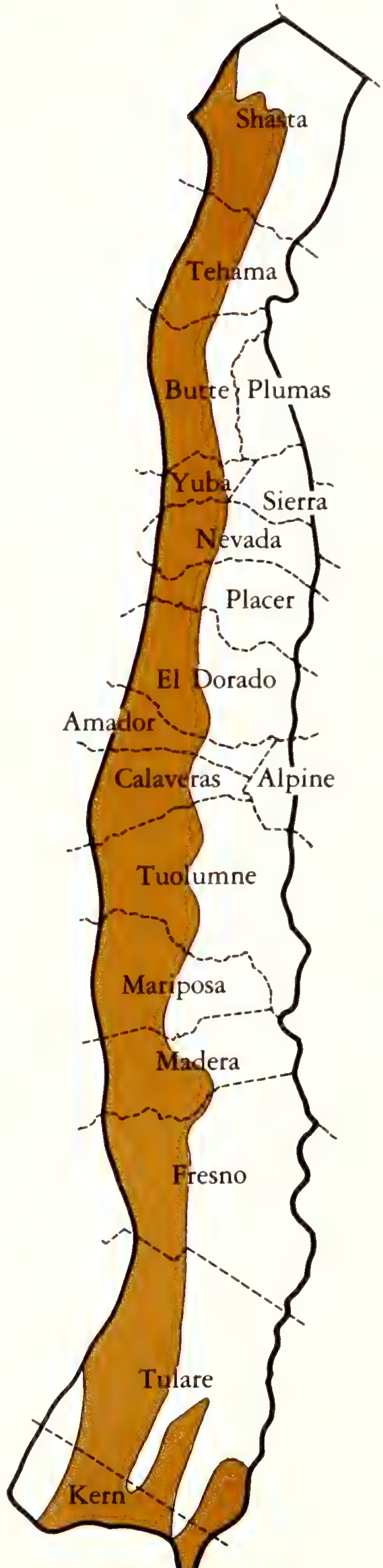
TERRITORY/HOME RANGE: Home range and territory the same. In Los Angeles County, 65 territories averaged 5.8 acres (2.4 ha), with range from 2.5 to 17 acres (1.0 to 6.9 ha) (Cogswell 1962). In an Oregon oak woodland, Kroodsma (1973) studied 34 territories, finding a range from 3.1 to 11.8 acres (1.3 to 4.8 ha) and an average of 5.7 acres (2.3 ha).

FOOD HABITS: Gleans small insects from low limbs and branches, under dense cover.

OTHER:

REFERENCES: Miller 1941, Cogswell 1962, Kroodsma 1973.





Long-billed Marsh Wren

B132 *(Cistothorus palustris)*

STATUS: No official listed status. Rare transient at lower altitudes in late summer and early fall. No breeding records above 1000 ft (305 m).

DISTRIBUTION/HABITAT: Prefers cattails, bulrushes, or other emergent wetland vegetation; sometimes feeds in drier upland sites near water during migration or winter periods. In the western Sierra Nevada, recorded in late summer to early fall in marsh or marsh-like habitats in all vegetation types from annual grasslands up to mixed-conifer zone.

SPECIAL HABITAT REQUIREMENTS: Marsh.

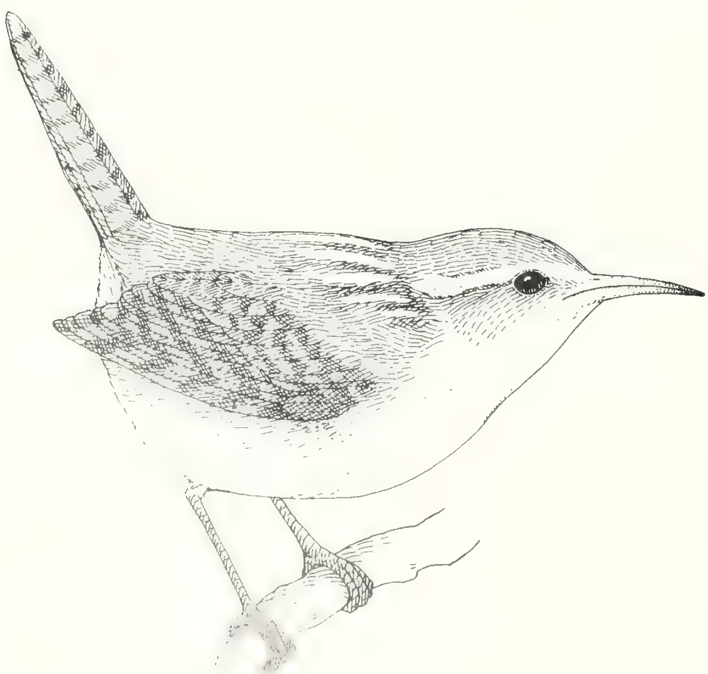
BREEDING: Does not breed in the western Sierra Nevada.

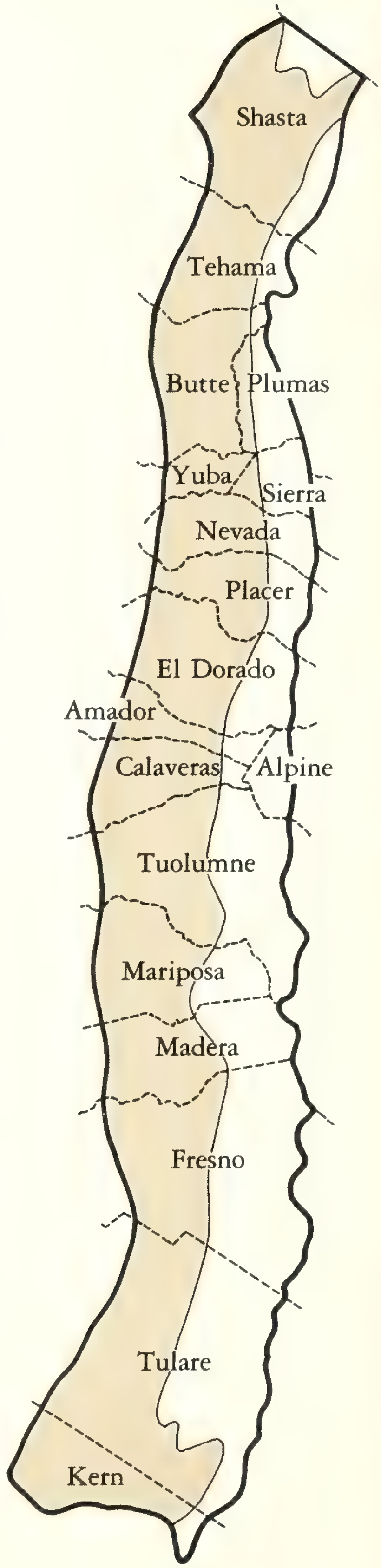
TERRITORY/HOME RANGE: Probably none established in the western Sierran zone.

FOOD HABITS: Eats insects, spiders, and other small invertebrates found in habitat. Gleans food from emergent vegetation, damp ground, and water surface. Sometimes hawks for aerial insects.

OTHER:

REFERENCES: Welter 1935, Kale 1965, Verner 1965.





Cañon Wren

B133 (*Catherpes mexicanus*)

STATUS: No official listed status in our area. Uncommon resident in suitable habitat.

DISTRIBUTION/HABITAT: Prefers cool, shaded canyons with exposed rock outcrops. May be found in any habitat type from annual grasslands up to Jeffrey pine forests, but confined to canyons in all types and usually found in the vicinity of water. More common at lower elevations.

SPECIAL HABITAT REQUIREMENTS: Small cliffs, talus, or rock outcrops.

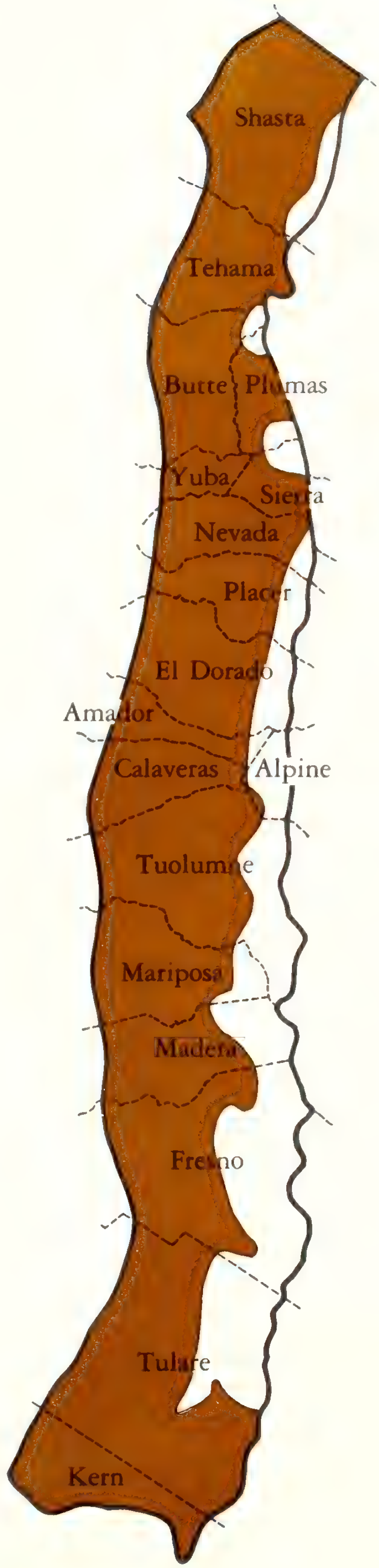
BREEDING: Breeds from mid-March to mid-August, with peak from early May to late June. Clutch size from 4 to 6, most contain 5 or 6. Nests on ledge in rock cavern, in crevice in cliff or bank, or attaches nest to rock face in cave or wide crevice.

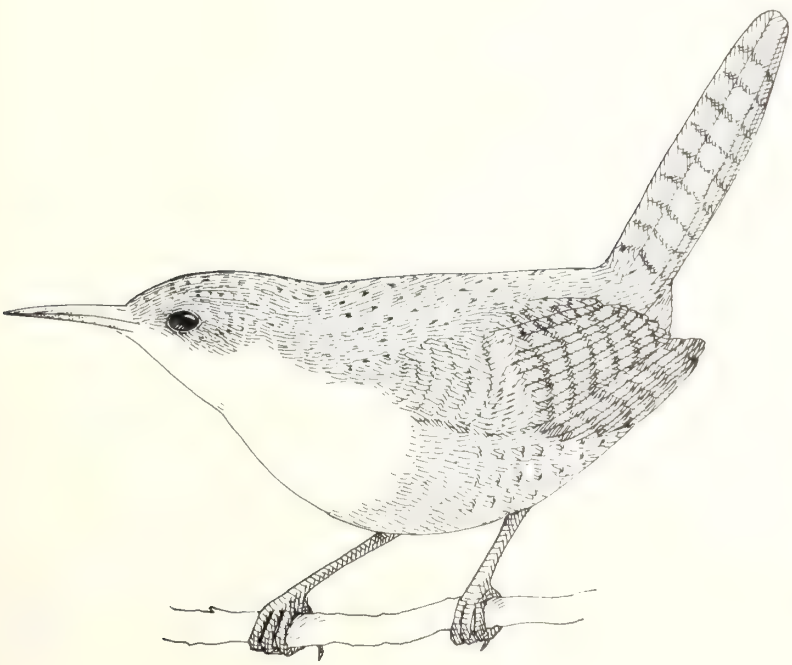
TERRITORY/HOME RANGE: Unknown.

FOOD HABITS: Gleans insects and spiders from surfaces of rock or earth, often in concealed situations. Hops or creeps while searching for food.

OTHER:

REFERENCES: Tramontano 1964.





Rock Wren

B134 *(Salpinctes obsoletus)*

STATUS: No official listed status. Fairly common resident in suitable habitat.

DISTRIBUTION/HABITAT: Inhabits rock outcrops, talus slopes, fractured cliff faces, and dry earth banks. Requires rough surface with crevices for foraging and cover. On west slopes of the Sierra Nevada, most common below montane coniferous forest and above timberline. Altitude of winter range unknown.

SPECIAL HABITAT REQUIREMENTS: Talus; rock outcrops.

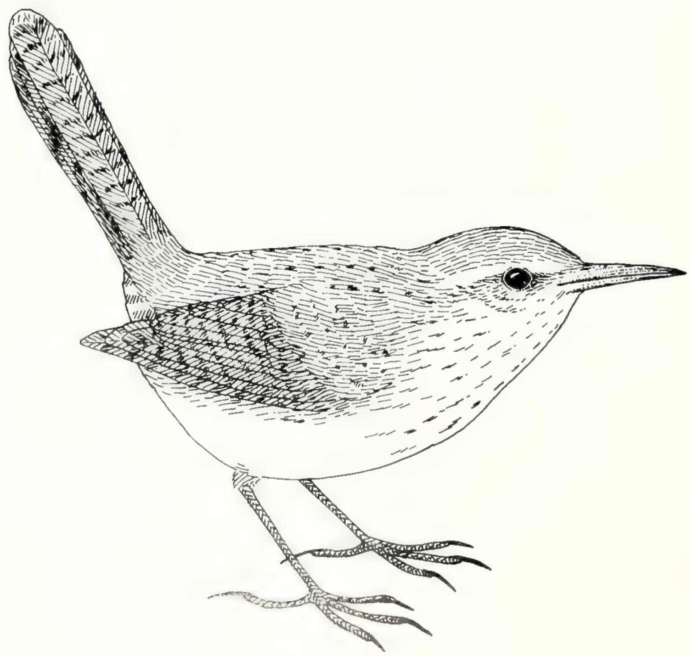
BREEDING: Breeds from early February to early September, with peak from early May to early July (may rear two broods per season). Clutch size from 4 to 10, most contain 5 or 6. Nests under large boulders, in rodent cavities in banks, or in cavities and crevices among loose rocks.

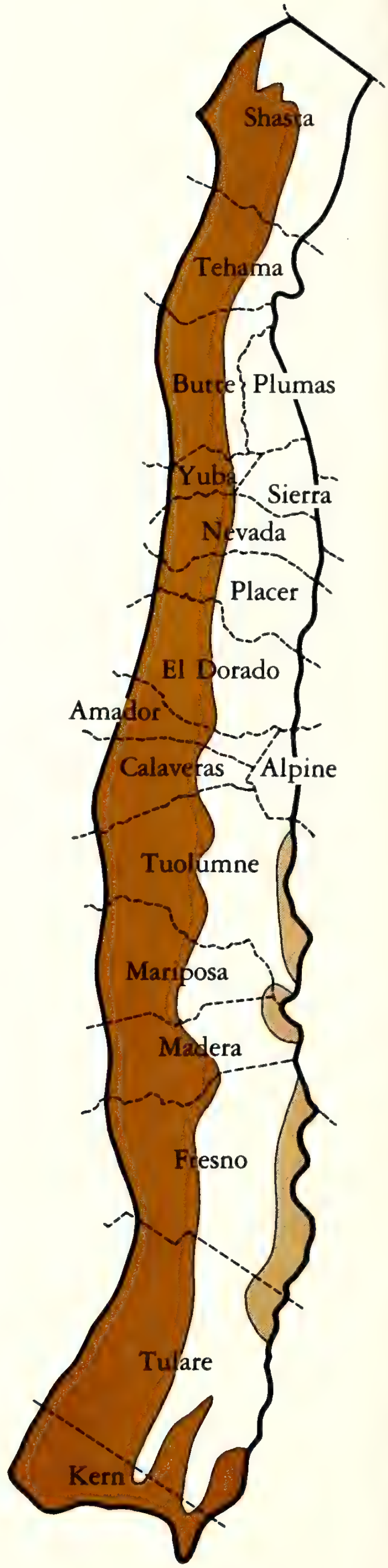
TERRITORY/HOME RANGE: Unknown, although Ainley (1971) reported a pair foraged from 16 to 164 ft (4.9 to 50 m) from nest on Farallone Islands.

FOOD HABITS: Gleans insects and spiders from boulders, rocks, barren ground, in the open or in crevices. Runs while searching for food.

OTHER: Tolerates extremely arid conditions.

REFERENCES: Tramontano 1964.





Mockingbird

B135 *(Mimus polyglottos)*

STATUS: No official listed status. Uncommon resident at lower elevations in the western Sierra Nevada.

DISTRIBUTION/HABITAT: Found in shrub and early tree stages of oak, digger pine-oak, and chaparral types. The upper altitudinal limit unclear from literature; probably resident locally but not common above 1000 ft (305 m). Often found in residential areas, agricultural areas, and edges of brushland and woodland.

SPECIAL HABITAT REQUIREMENTS: Trees/shrubs.

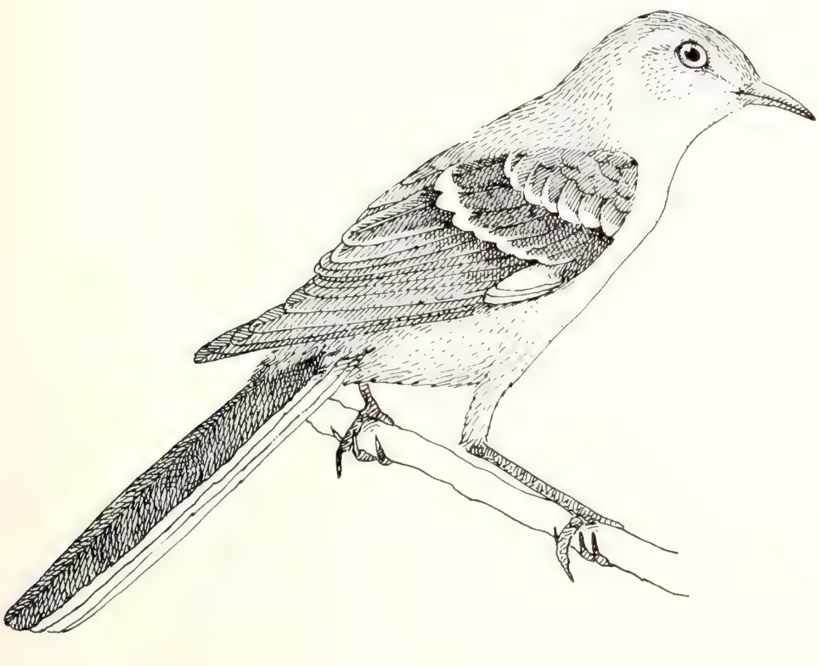
BREEDING: Breeds from early February to mid-September, with peak from early May to early July (usually two broods per season). Clutch size from 3 to 6, with 4 or 5 most common. Nests in variety of shrubs, small trees, or tangles of vines, usually below 6 ft (2 m), but occasionally as high as 40 ft (12 m).

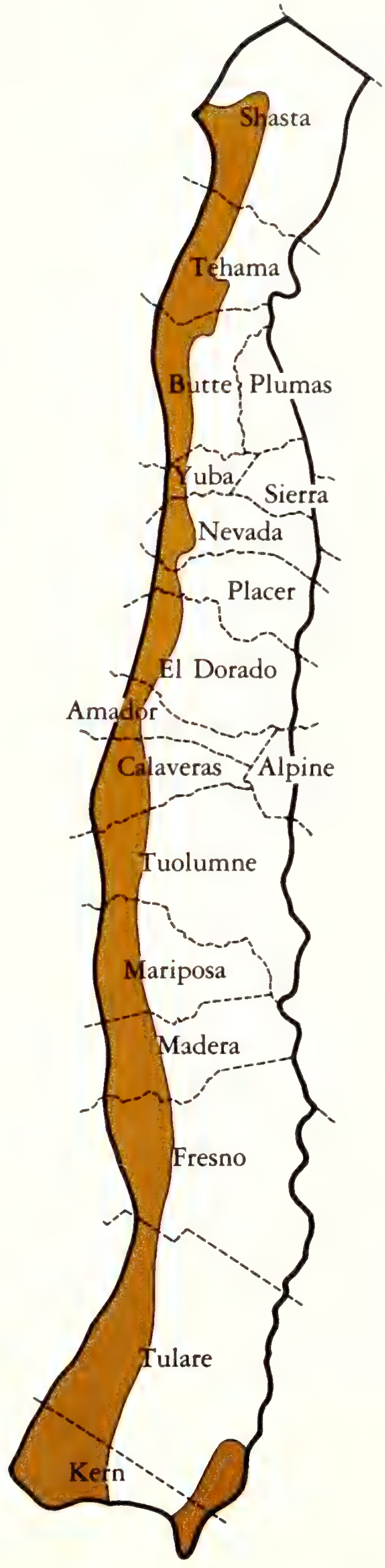
TERRITORY/HOME RANGE: Home range and territory the same. Five breeding territories studied in residential area in Pasadena averaged 1 acre (0.4 ha), with range from 0.6 to 1.4 acres (0.2 to 0.6 ha) (Michener and Michener 1935). In Arizona desert, Hensley (1954) reported two territories at 7.1 and 8.2 acres (2.9 and 3.3 ha), and in Texas, Howard (1974) found range among 10 territories of 1.5 to 6.2 acres (0.6 to 2.5 ha) with mean of 2.8 acres (1.1 ha).

FOOD HABITS: Eats mainly insects during breeding season and fruit and insects in nonbreeding period. Takes insects from ground by dropping from perch; gleans from foliage; and hawks from the air.

OTHER:

REFERENCES: Michener and Michener 1935, Laskey 1962, Adkisson 1966.





California Thrasher

B136 *(Toxostoma redivivum)*

STATUS: No official listed status. Fairly common permanent resident in suitable habitat.

DISTRIBUTION/HABITAT: Breeds in brush and early tree stages in blue oak savannah, digger pine-oak, chaparral, and riparian deciduous types. Avoids dense tree canopies.

SPECIAL HABITAT REQUIREMENTS: Dense shrubs.

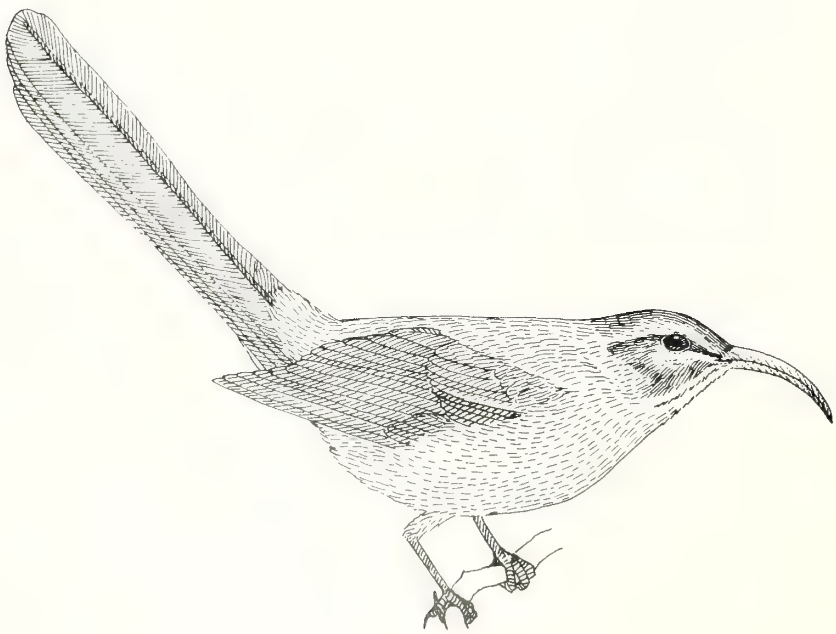
BREEDING: Breeds from early December to early August, with peak from mid-April to mid-June. Usually rears two broods per season. Clutch size from 2 to 4, most contain 3. Nests near ground, well inside large bush or scrubby tree, screened from outside view.

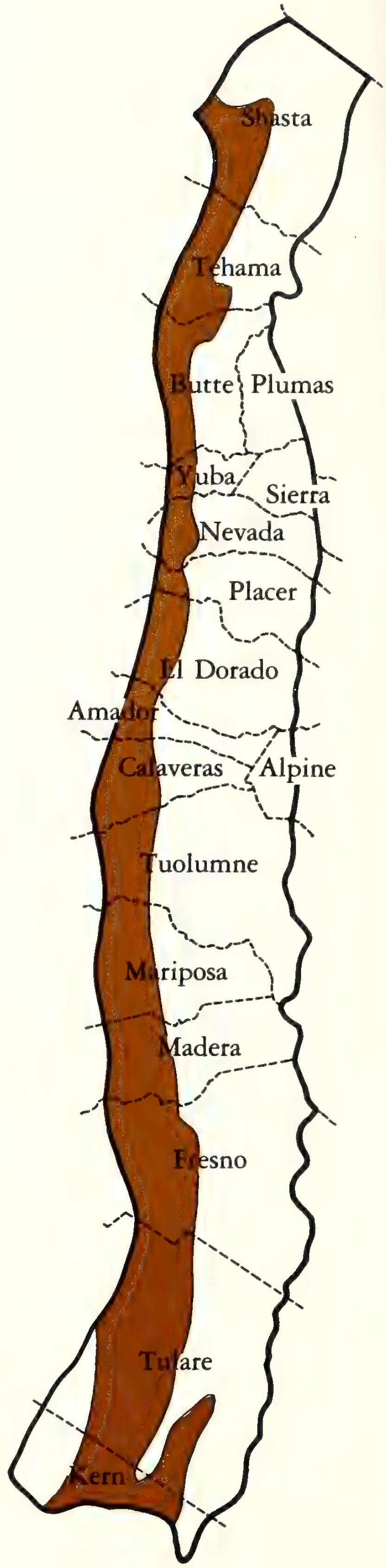
TERRITORY/HOME RANGE: Territory and home range the same. Four territories studied during breeding season in Santa Monica Mtns., Los Angeles County, in chaparral, averaged 3.5 acres (1.4 ha) (Kingery 1962).

FOOD HABITS: Takes insects, spiders, fruits, and seeds from plant litter and soft soil. Rakes away litter with bill, digs in litter or soil, and picks fruit from shrubs.

OTHER: No detailed, recent life history study.

REFERENCES: Sargent 1940, Kingery 1962.





American Robin

B137 *(Turdus migratorius)*

STATUS: No official listed status. Abundant year-round, with some seasonal absences at lower elevations in spring and summer and at higher elevations in winter.

DISTRIBUTION/HABITAT: Breeds in forested sites from ponderosa pine, black oak woodland zone up to lodgepole pine forests. Prefers areas with low percent canopy coverage. Congregates where ripening fruit abundant. Forms large flocks in nonbreeding period, and few may winter at high elevations, for example, Tuolumne Meadows, in Yosemite National Park (T. Hargis, pers. commun.).

SPECIAL HABITAT REQUIREMENTS: Water (for mud in nest building); openings.

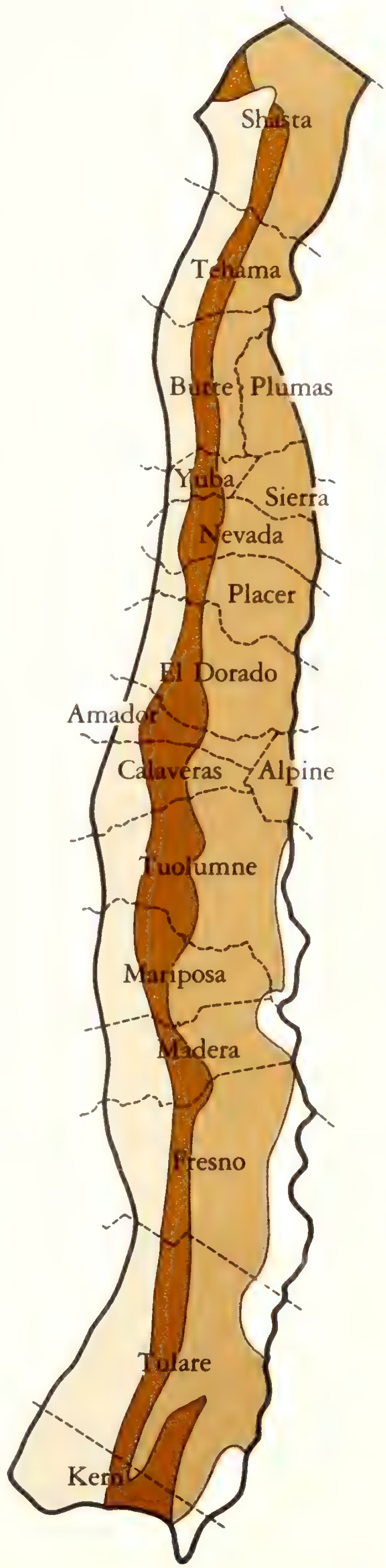
BREEDING: Breeds from early April to mid-July, with peak from mid-May to mid-June. Nests on limbs of conifers or broadleaved trees, or in large shrubs, usually in or near clearings. Nest height ranges from 1 to 75 ft (0.3 to 23 m); most between 10 and 15 ft (3.1 and 4.6 m). Clutch size from 3 to 4, with mean of 3.5.

TERRITORY/HOME RANGE: In Massachusetts, home range averaged about 1320 ft (400 m) radius around nest (Hirth *et al.* 1969). In Wisconsin territories ranged from 4800 to 26,000 ft^2 (445 to 2420 m^2), with average of 13,000 ft^2 (1210 m^2) (Young 1951).

FOOD HABITS: Earthworms and insects (70 percent of diet); seeds, berries, fruit, stems, and grass blades (30 percent). Searches on the ground, probing and scratching for food; also picks berries.

OTHER:

REFERENCES: Grinnell and Storer 1924, Howell 1942, Bent 1949.



Varied Thrush

B138 (*Ixoreus naevius*)

STATUS: No official listed status. Irregular fall and winter visitor to low and middle elevations; fall migrant at higher elevations.

DISTRIBUTION/HABITAT: Found sparingly in fall from blue oak savannahs up to lodgepole pine forests, and in winter from ponderosa pine and black oak woodlands downward. Numbers fluctuate widely from year-to-year in response to berry production.

SPECIAL HABITAT REQUIREMENTS:

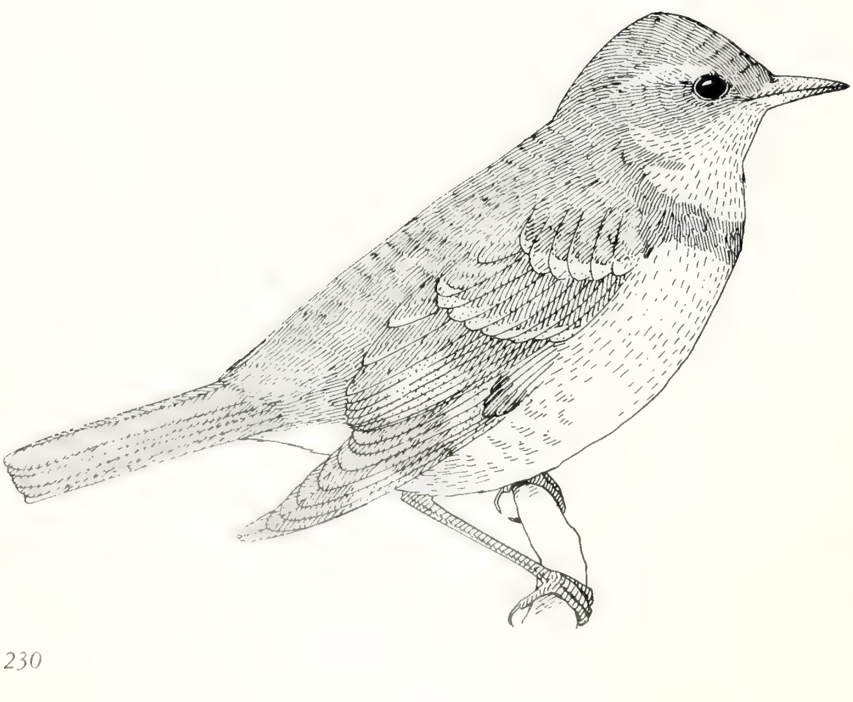
BREEDING: Does not breed in the western Sierra Nevada.

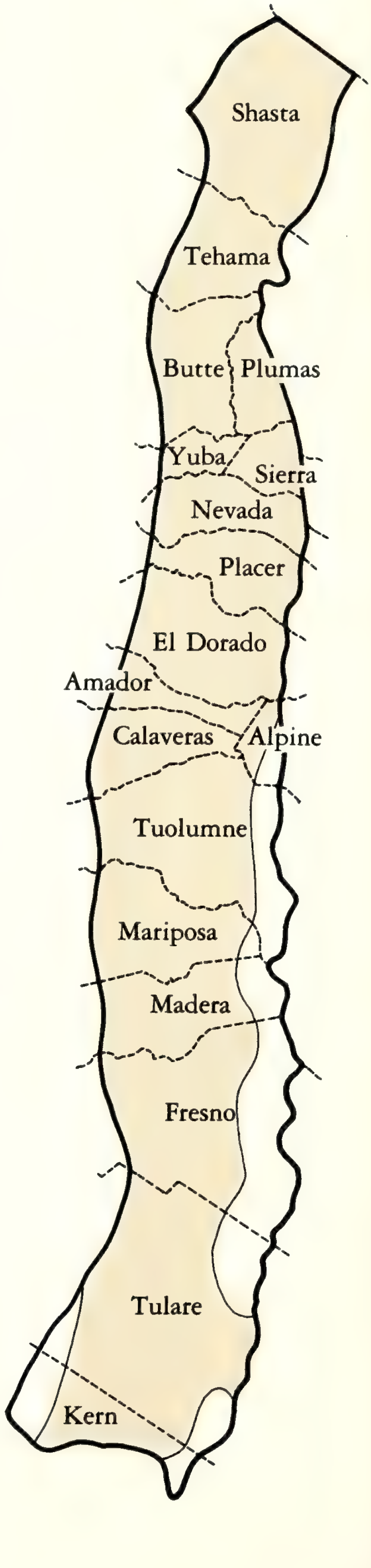
TERRITORY/HOME RANGE: No data on home range; not territorial in fall and winter.

FOOD HABITS: Takes berries (for example, toyon, manzanita), seeds, mast, insects, and spiders from the ground, from foliage by gleaning, and from fruiting stems.

OTHER:

REFERENCES: Grinnell and Miller 1944, Bent 1949, Martin 1970.





Hermit Thrush

B139 *(Catharus guttata)*

STATUS: No official listed status. Common summer resident at middle and high elevations; fall visitor at all elevations; and fairly common winter resident below snow level.

DISTRIBUTION/HABITAT: Breeds in forested sites from ponderosa pine and black oak woodland types up to lodgepole pine forests, especially at higher elevations and in forests with intermediate to high percent canopy coverage. In fall and winter, ranges downslope as far as blue oak savannahs. Absent in winter in mixed-conifer and higher forests.

SPECIAL HABITAT REQUIREMENTS:

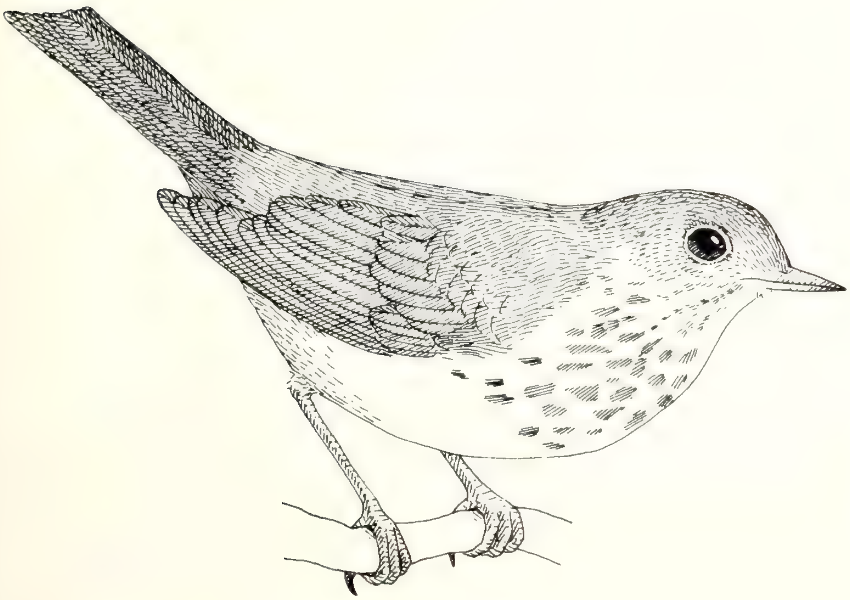
BREEDING: Breeds from mid-May to late July, with peak from late May to late June. Nests usually 2 to 15 ft (0.6 to 4.6 m) above ground in shaded groves of small trees with open views from nest. Occasionally nests on the ground. Clutch size from 3 to 5, with mean of 4.

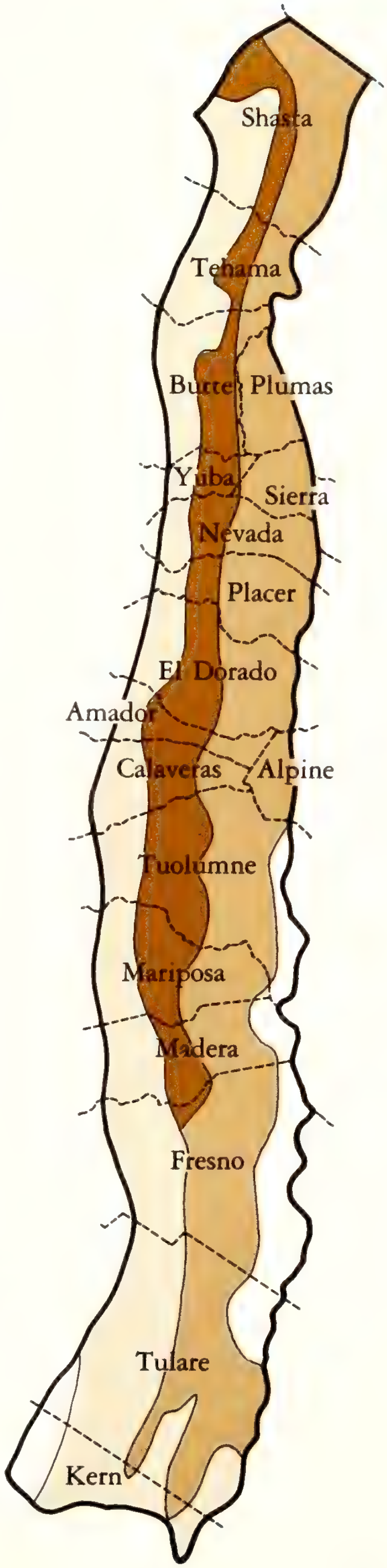
TERRITORY/HOME RANGE: No data on home range or territory size, but in burned-over area in Michigan, Pettingill (1930) reported breeding density of 6 nests/mi^2 (2.3 nests/km^2).

FOOD HABITS: Eats insects, spiders, fruit, berries, and seeds (especially those of poison oak). Searches for food on ground, without scratching, on dry slopes, around meadows, and on forest floor, seldom far from cover.

OTHER: Breeding hermit thrushes in the Sierra Nevada do not remain all year; replaced in fall and winter by migrants from the north.

REFERENCES: Grinnell and Storer 1924, Grinnell and Miller 1944, Bent 1949.





Swainson's Thrush

B140 *(Catharus ustulata)*

STATUS: No official listed status. Historically, locally common nesting species at low and middle elevations; presently rare and local. Reason for decline unknown (Gaines 1977).

DISTRIBUTION/HABITAT: Breeds locally in small numbers in timbered areas of ponderosa pine, black oak woodland, riparian deciduous, and mixed-conifer types. Prefers dense thickets near streams or wet meadows. Recorded rarely as nonbreeder in spring and summer in oak types at lower elevations.

SPECIAL HABITAT REQUIREMENTS: Trees/shrubs near water.

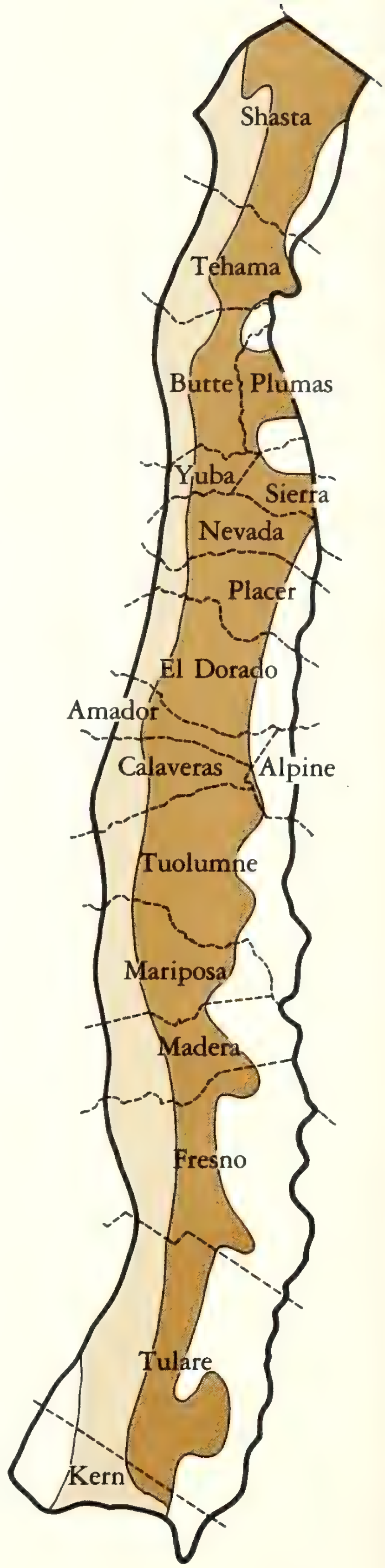
BREEDING: Breeds from mid-April to mid-July, with peak from early May to early June. Nests in shrub or small tree, usually in coniferous forest or low brushy thicket, near source of water. Nest height ranges from 2 to 8 ft (0.6 to 2.4 m) above ground. Clutch contains from 3 to 5 eggs, with mean of 4.

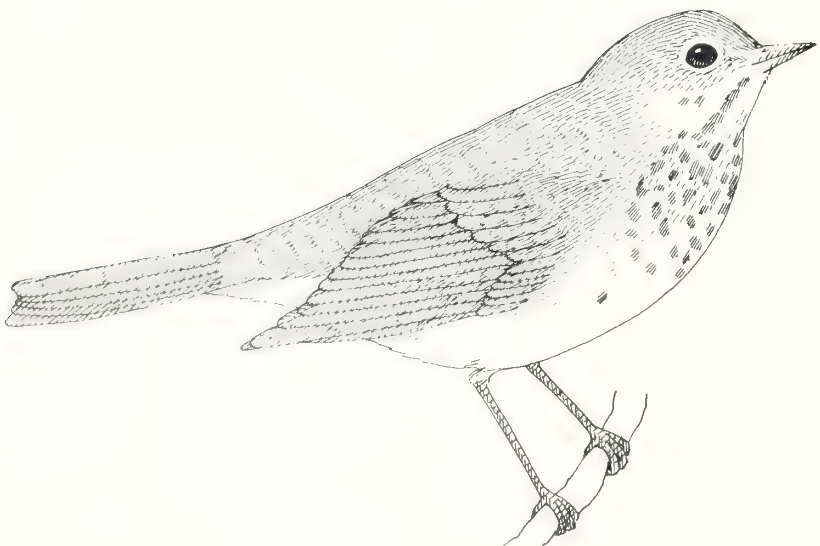
TERRITORY/HOME RANGE: No data available.

FOOD HABITS: Eats mostly insects and spiders, and some berries in breeding season. Searches and probes on the forest floor, especially in undisturbed conifer forests. Gleans foliage, and occasionally hawks aerial insects.

OTHER: Thought to be competitively excluded by hermit thrushes in Maine (Morse 1972) and British Columbia (Sealy 1974). May be a factor in decline in numbers in the Sierra Nevada, but not known.

REFERENCES: Grinnell and Storer 1924, Grinnell and Miller 1944, Bent 1949.





Western Bluebird

B141 *(Sialia mexicana)*

STATUS: No official listed status; on the 1978 Audubon Society Blue List. Common permanent resident at lower elevations, and summer-fall resident at higher elevations.

DISTRIBUTION/HABITAT: Breeds from blue oak savannahs up to Jeffrey pine forests; prefers stands with low percent canopy cover. Generally a bird of open country with standing dead trees available; edge situations ideal. At higher elevations, often nests in logged or burned areas; usually nests below 4000 ft (1220 m) elevation, though occasionally as high as 8000 ft (2440 m) (Gaines 1977). In fall, drifts upslope or migrates southward to higher elevation oak forests; feeds on mistletoe berries, sometimes in flocks numbering 50 or more birds.

SPECIAL HABITAT REQUIREMENTS: Nest cavities; medium to large openings.

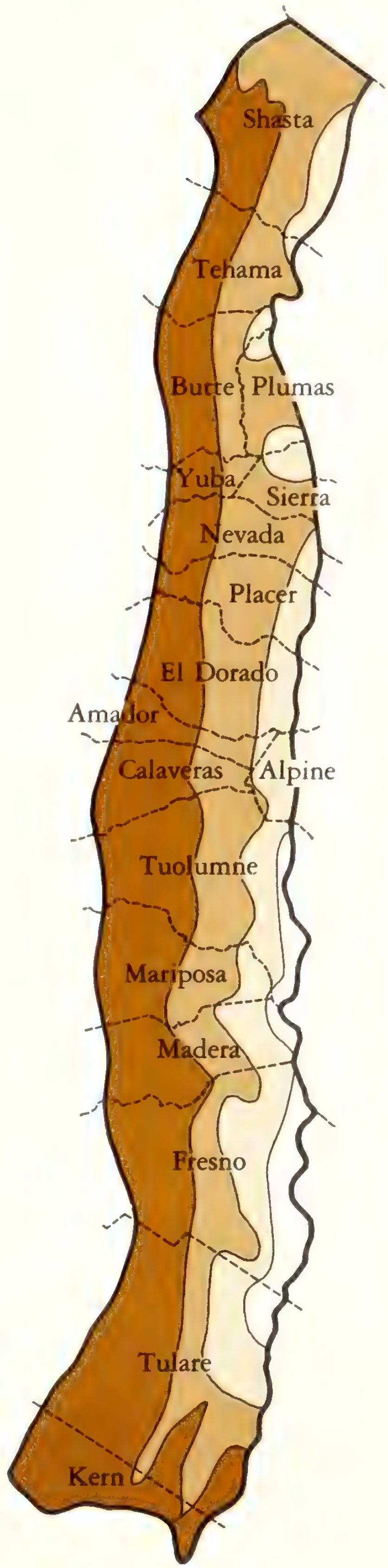
BREEDING: Breeds from late April to early July, with peak from mid-May to mid-June. Nests in holes in standing dead trees or stumps. Nest height varies from 5 to 40 ft (1.5 to 12 m). Clutch size from 3 to 8, with mean of 5.

TERRITORY/HOME RANGE: No data available.

FOOD HABITS: Eats primarily insects; also eats berries of mistletoe, poison oak, and elderberry during nonbreeding period. Takes food from ground by sitting on slightly elevated perch and dropping down to pounce on insects. Also hawks aerial insects and picks berries from shrubs.

OTHER:

REFERENCES: Grinnell and Storer 1924, Bent 1949, Jackman and Scott 1975.



Mountain Bluebird

B142 *(Sialia currucoides)*

STATUS: No official listed status. Fairly common spring and summer resident at higher elevations, moving to foothills in fall.

DISTRIBUTION/HABITAT: Breeds in lodgepole pine forests, and sparingly down to mixed-conifer type; prefers open sites with low percent canopy coverage. Requires some brush in nesting territories; prefers open, treeless terrain of subalpine for foraging. Fire and logging activities at high elevations favor species. Spends most of nonbreeding period in foothill oak woodlands.

SPECIAL HABITAT REQUIREMENTS: Nest cavities; medium to large openings.

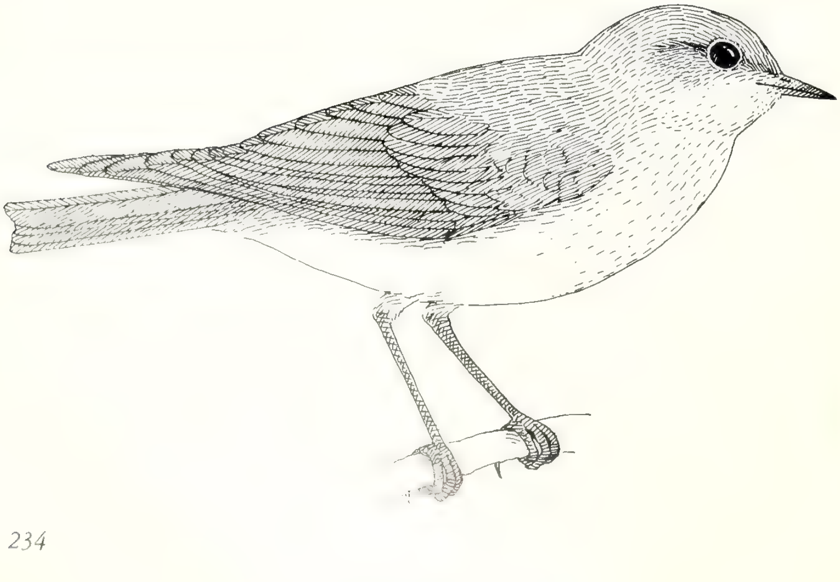
BREEDING: Breeds from mid-April to mid-July, with peak from mid-June to early July. Nests located in cavity, often abandoned woodpecker hole, in standing dead tree or stub. Clutch size from 4 to 8, with mean of 6.

TERRITORY/HOME RANGE: Insufficient data. A female feeding young on Mt. Rainier, Washington, reportedly foraged over circular area with diameter of about 600 ft (185 m) (Jewett *et al.* 1953). In his Montana study, Power (1966) noted that smallest "territory" was about 300 ft (91 m) wide, although some individuals foraged up to 1320 ft (400 m) from nest.

FOOD HABITS: Eats mostly insects, also fruit in late summer. Takes insects from foliage, from air, and occasionally from ground. Most foraging done from perch, hawking aerial insects and pouncing on items spotted on ground. Occasionally, hovers to search ground for food.

OTHER: Mountain and western bluebirds generally altitudinally separated in breeding ranges, with mountain at higher elevations and western at lower elevations. Observed nesting, however, in the same forest openings.

REFERENCES: Bent 1949, Power 1966, Jackman and Scott 1975.



Townsend's Solitaire

B143 *(Myadestes townsendi)*

STATUS: No official listed status. Fairly common summer resident to mid- and high-elevation forests, winters at lower elevations.

DISTRIBUTION/HABITAT: Breeds in coniferous forests from ponderosa pine type up to lodgepole pine forests, especially in mid-elevation types. Prefers stands with low percent canopy cover. In fall, disperses both up- and downslope in search of ripening fruit and other foods, descending into oak groves in fall, coincident with ripening of mistletoe berries.

SPECIAL HABITAT REQUIREMENTS:

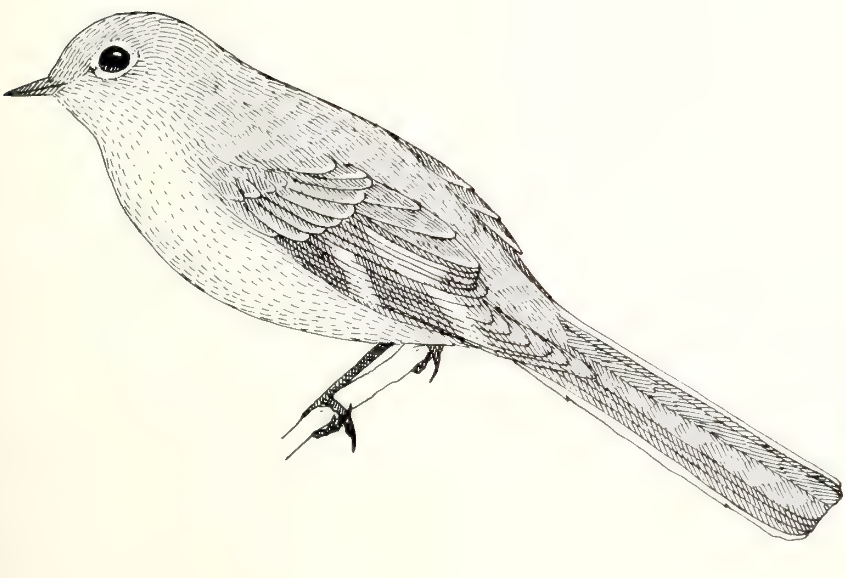
BREEDING: Breeds from early May to early August, with peak from late May to late June. Nests usually on or near ground, as in road cut, rock crevice, or at base of large tree; some type of overhanging shelter required. Clutch size from 3 to 5, with a mean of 4.

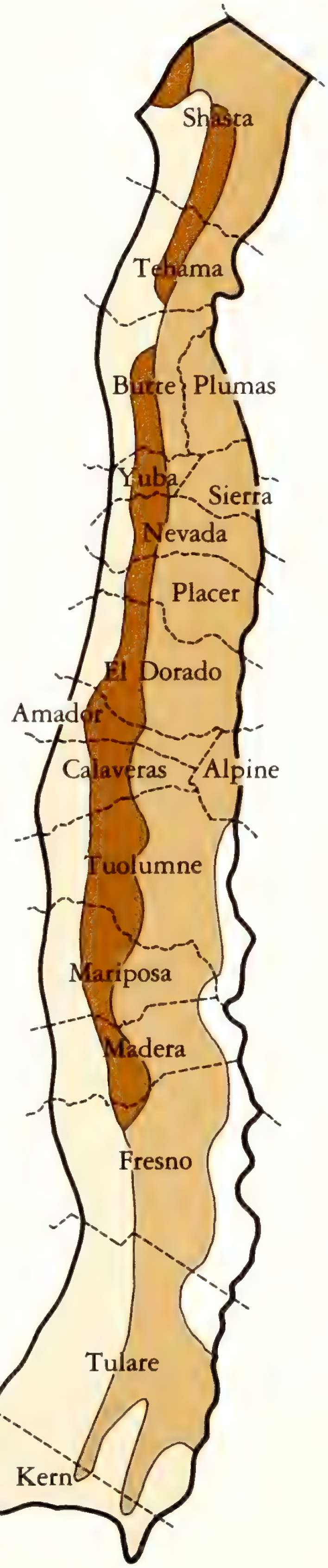
TERRITORY/HOME RANGE: No data on home range or size of breeding territory. In northern California, Dawson (1919) reported an approximate density of breeding territories of $4/mi^2$ ($1.54/km^2$). In an Arizona piñon-juniper-ponderosa pine ecotone, Salomonson and Balda (1977) reported mean winter territory sizes of 1.75 acres (0.7 ha) (four territories) during winter 1973-74, and 9.5 acres (3.85 ha) (three territories) during winter 1974-75.

FOOD HABITS: Eats insects, fruits, mistletoe berries, and other foods. Takes food from air, ground, foliage, and fruiting stems. Usually from perch in shade, hawks for aerial insects or pounces on objects on ground.

OTHER: During nonbreeding period, solitaires commonly gather into moderate-sized flocks. Can be heard in full song throughout fall and into winter.

REFERENCES: Grinnell and Storer 1924, Grinnell and Miller 1944, Bent 1949.





Blue-gray Gnatcatcher

B144 (*Polioptila caerulea*)

STATUS: No official listed status. Common summer resident.

DISTRIBUTION/HABITAT: Breeds in blue oak savannah, digger pine-oak, chaparral edges where mingled with oak, and in riparian deciduous if adjacent to oak woodland or chaparral. Prefers stands with low to intermediate percent canopy cover. In late summer, moves upslope as far as mixed-conifer zone.

SPECIAL HABITAT REQUIREMENTS: Oaks in breeding season.

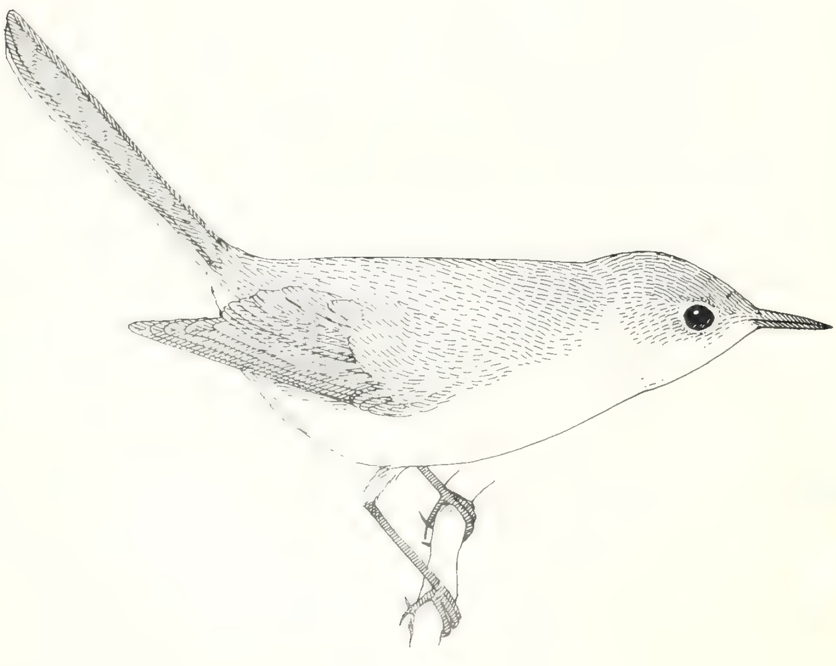
BREEDING: Breeds from early April to early August, with peak from mid-May to early July. Nests in live tree or shrub, usually near top, in fork between two branches. Nest height ranges from 3 to 45 ft (0.9 to 14 m) up. Clutch size from 3 to 5, with 4 most frequent.

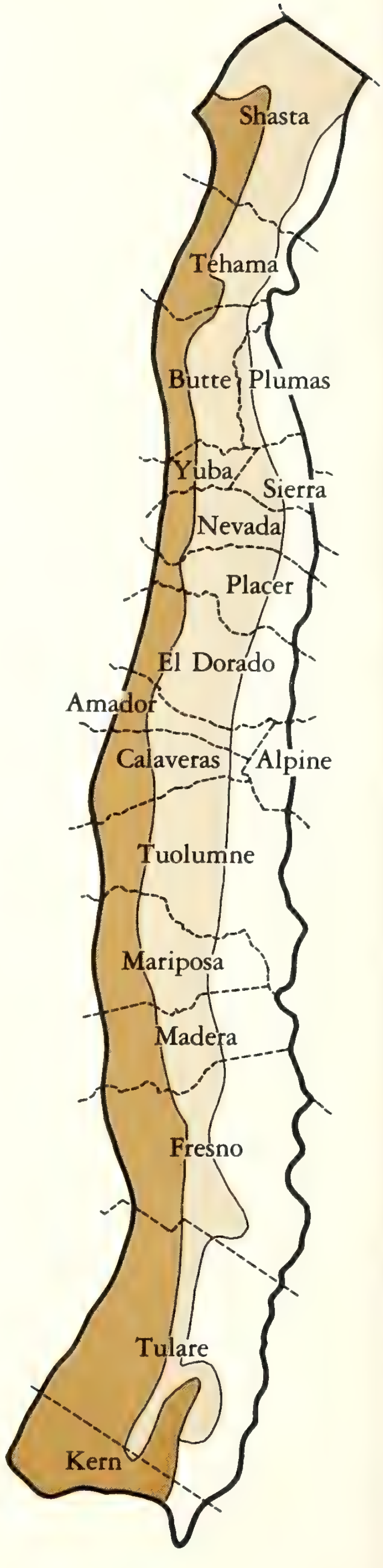
TERRITORY/HOME RANGE: Territory and home range the same. In Monterey County, breeding territories ranged from 2.2 to 7.4 acres (0.9 to 3 ha), with mean of 4.6 acres (1.9 ha) (Root 1969). In Arizona desert, winter home range appeared to be at least 22 acres (8.9 ha); in "an isolated screw-bean *(Prosopis pubescens)* woodland near Yuma, Arizona, at least nine gnatcatchers . . . were found within an area of 22 acres" (Root 1969). Each bird confined activities to area of about 3 acres (1.2 ha) or less.

FOOD HABITS: Feeds exclusively on small insects and spiders. Mostly gleans from foliage, twigs, and small branches of trees and shrubs; also from grasses and herbs. Also hovers to pick food from surfaces, and hawks for aerial insects.

OTHER:

REFERENCES: Bent 1949; Root 1967, 1969.





Golden-crowned Kinglet

B145 *(Regulus satrapa)*

STATUS: No official listed status. Abundant resident and breeder.

DISTRIBUTION/HABITAT: Breeds in conifer forests with intermediate to high percent canopy cover, from ponderosa pine to red fir forests. Some remain at high elevations all year; many move downslope into oak woodlands and riparian deciduous vegetation. Prefers dense, shaded forests, especially of red or white fir, or Douglas-fir.

SPECIAL HABITAT REQUIREMENTS:

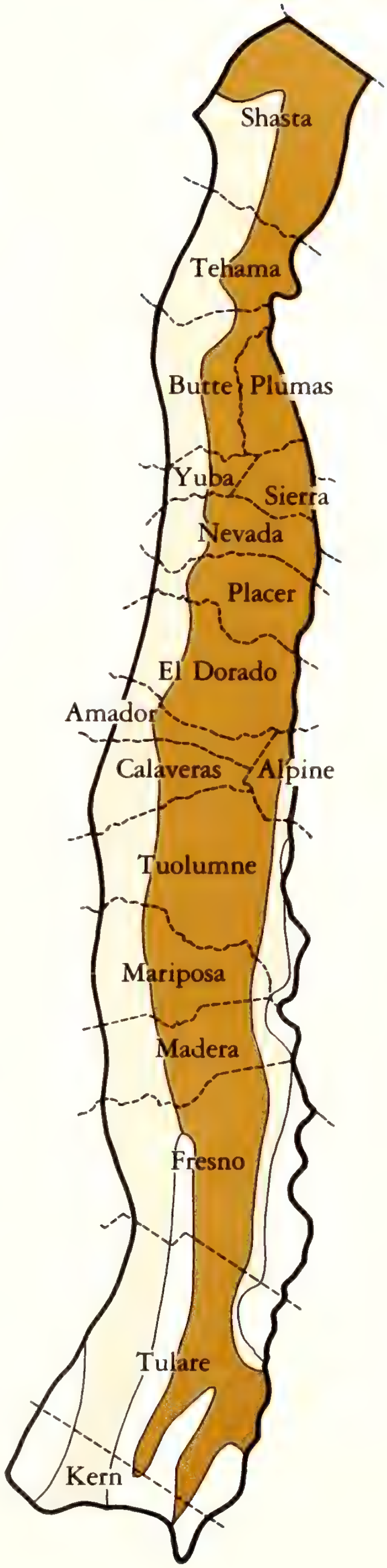
BREEDING: Breeds from early April to late July, with peak from late May to early July. Nests concealed in foliage of tips of branches or in clusters of live, hanging twigs. Recorded nest heights range from 5 to 50 ft (1.5 to 15 m), but probably nest much higher—the nests difficult to detect. Clutch size from 5 to 11, most contain 8 or 9.

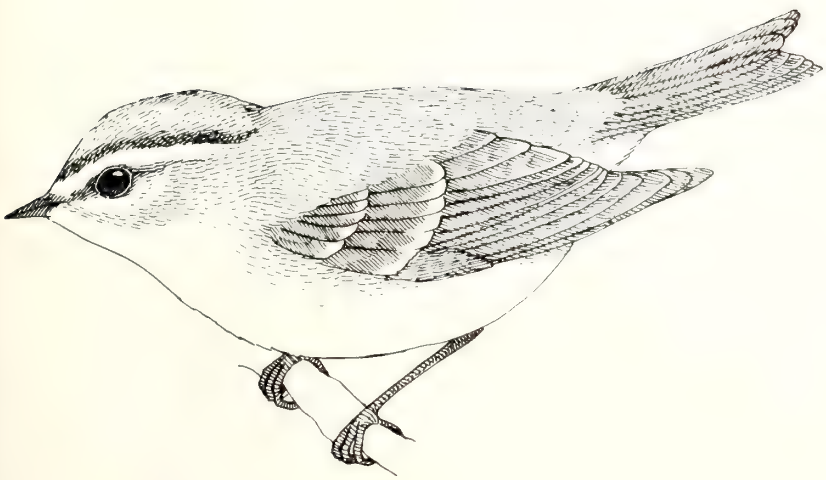
TERRITORY/HOME RANGE: No information available.

FOOD HABITS: Feeds on small insects, gleaned from foliage and small twigs, usually in well-shaded site. Usually hovers to glean items from vegetation.

OTHER:

REFERENCES: Grinnell and Miller 1944, Bent 1949, Gaines 1977.





Ruby-crowned Kinglet

B146 *(Regulus calendula)*

STATUS: No official listed status. Common summer resident and breeder; abundant winter visitor at lower elevations.

DISTRIBUTION/HABITAT: Breeds in timbered areas with low to intermediate percent canopy cover, from mixed-conifer up to lodgepole pine forests. Prefers lodgepole forest for breeding, especially in open stands or near edge, such as along stream or meadow. In late summer and early fall, migrants occur to treeline. In winter, present only at lower elevations in a variety of habitats.

SPECIAL HABITAT REQUIREMENTS:

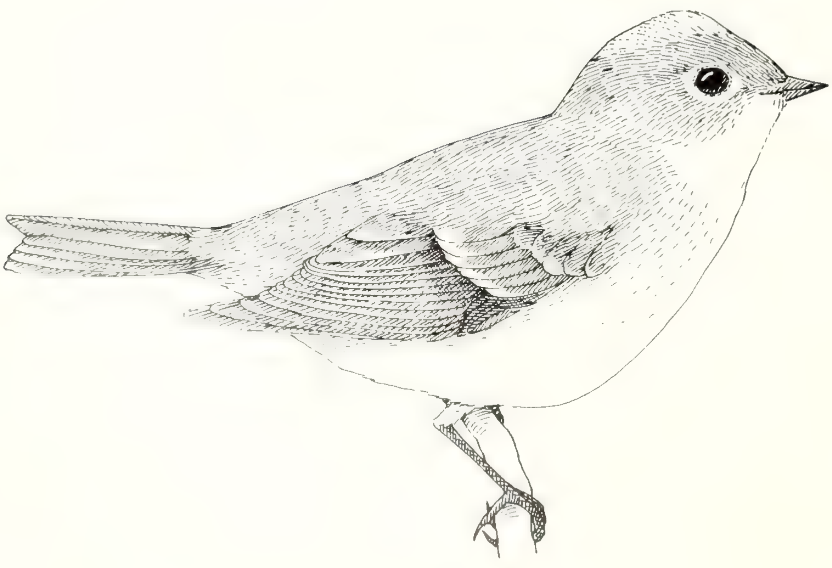
BREEDING: Breeds from mid-May to mid-August, with peak from mid-June to late July. Builds hanging nest attached to twigs of conifer foliage, usually near tip of branch far above the ground. Nest height ranges from 2 to 100 ft (0.6 to 31 m). Clutch size from 5 to 11, most contain 7 to 9.

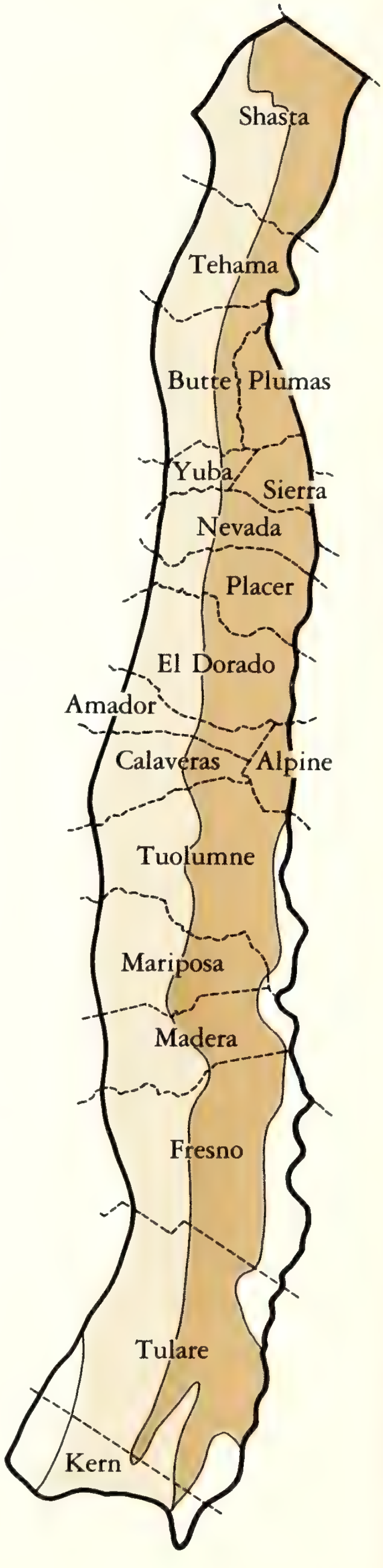
TERRITORY/HOME RANGE: No information on home range. In San Diego County, two winter territories covered 0.5 and 1 acre (0.2 and 0.4 ha) (Rea 1970). Nonterritorial in winter in some localities.

FOOD HABITS: Obtains small arthropods by gleaning foliage and bark, often by hovering.

OTHER:

REFERENCES: Grinnell and Miller 1944, Bent 1949, Gaines 1977.





Water Pipit

B147 *(Anthus spinoletta)*

STATUS: No official listed status. Common winter visitor at low elevations; rare late summer and fall migrant at all elevations.

DISTRIBUTION/HABITAT: Found in open country at all elevations in late summer and fall. Sighted rarely in summer above treeline in the Sierra Nevada. First Sierra Nevada nests discovered in 1975 and 1976 east of the crest, near Yosemite National Park. May also breed sparingly above treeline on west side. Move to lower elevations for late fall, winter, and spring periods.

SPECIAL HABITAT REQUIREMENTS: Open terrain.

BREEDING: Breeds from late June to early September, with peak from mid-July to mid-August. Nests on ground, usually sheltered by overhang of rock, sod, or vegetation. Avoids wet areas for nest placement. Clutch size from 3 to 6, with mean of 4.7.

TERRITORY/HOME RANGE: No data on home range. In a Wyoming alpine tundra, sizes of breeding territories ranged from 0.39 to 0.83 acre (0.16 to 0.34 ha), with an average of 0.45 acre (0.2 ha).

FOOD HABITS: Eats insects, gleaned from low vegetation, bare ground, and snowbanks.

OTHER:

REFERENCES: Pickwell 1947, Bent 1950, Verbeek 1970.

Cedar Waxwing

B148 (*Bombycilla cedrorum*)

STATUS: No official listed status. Winter visitor at low elevations; numbers and local occurrence vary widely from year-to-year; stragglers present throughout year; rare breeder.

DISTRIBUTION/HABITAT: Permanent resident in ponderosa pine and black oak woodland types; found in lower elevation oak types in all seasons except summer, and on up to the Jeffrey pine type in all seasons except winter. Only one confirmed breeding record located for the western Sierra Nevada, at Buck's Lake, Plumas County, at 5153 ft (1570 m) (see star on range map). Midsummer records in Yosemite and elsewhere indicate possible breeding. Prefers timbered sites with low percent canopy coverage; more common at lower elevations.

SPECIAL HABITAT REQUIREMENTS: Fruit, berries.

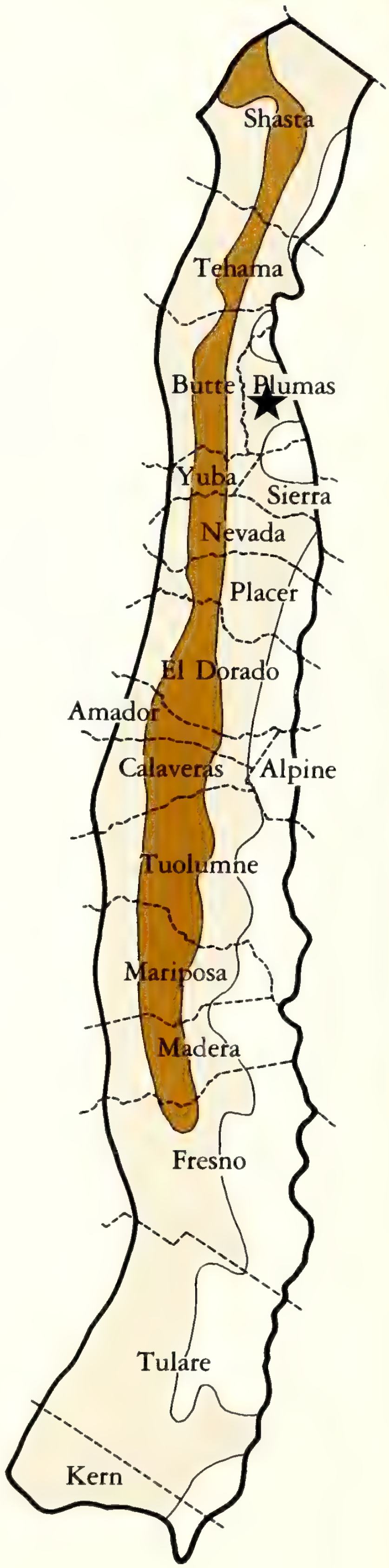
BREEDING: Breeds from early June to late August, with peak from late June to early August. Nests in tree or shrub, often at extreme end of branch. Nest height ranges from 5 to 50 ft (1.5 to 15 m) up, but usually below 20 ft (6.1 m). Clutch size from 3 to 6, with mean of about 4.

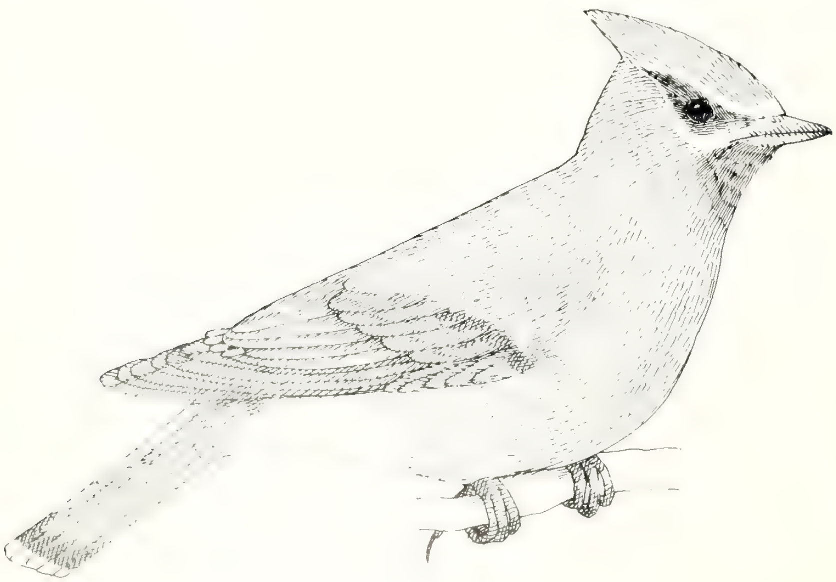
TERRITORY/HOME RANGE: No precise data on home range. In Ohio, three breeding territories ranged from 2025 to 9900 ft^2 (190 to 920 m^2), with average of 4770 ft^2 (440 m^2) (Putnam 1949).

FOOD HABITS: Fruit, berries, flowers, and buds, with some insects, comprise the diet. Picks and gleans food from living trees and shrubs, and often hawks insects.

OTHER: Nomadic, moving in flocks, and remaining only in areas with abundant food supply.

REFERENCES: Lea 1942, Putnam 1949, Bent 1950.





Phainopepla

B149 *(Phainopepla nitens)*

STATUS: No official listed status. Uncommon resident in foothills; rare in northern portion of the Sierra Nevada.

DISTRIBUTION/HABITAT: Breeds in blue oak savannahs, digger pine-oak woodlands, low elevation riparian deciduous, and chaparral types. Generally breeds in areas with scattered stands of small trees (usually oaks) surrounded by dense shrub understory. Recorded as high as 4000 ft (1220 m) in Yosemite Valley (Gaines 1977).

SPECIAL HABITAT REQUIREMENTS: Trees/shrubs; berries (especially mistletoe).

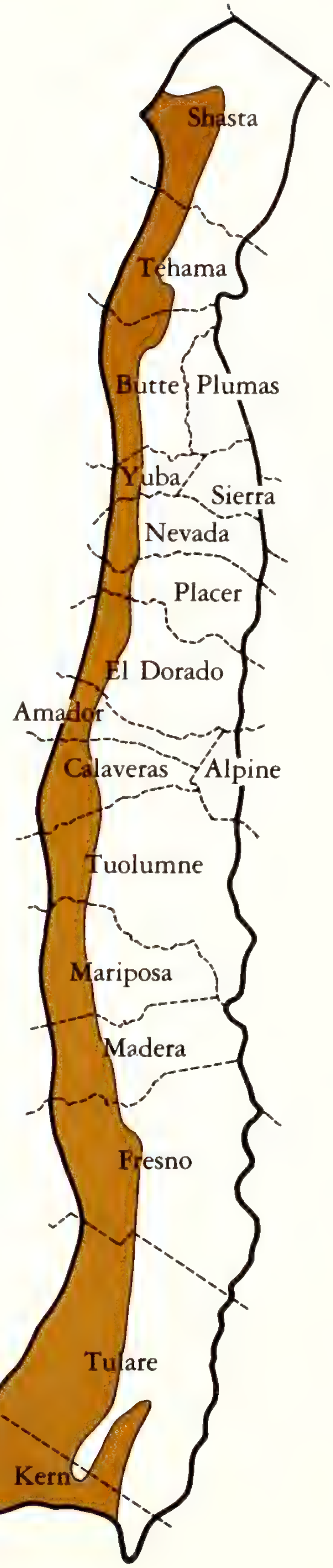
BREEDING: Breeds from late February to mid-July, with peak from late May to late July. Nests usually in dense foliage of shrubs, oaks, cottonwoods, willows, and others. Nest height ranges from 4 to 50 ft (1.2 to 15 m), most between 6 and 11 ft (1.8 and 3.4 m). Clutch size from 1 to 4, with mean of 2.5.

TERRITORY/HOME RANGE: No data on home range. Territory size in Imperial County ranged from 0.5 to 1.5 acres (0.2 to 0.6 ha), with mean of 1.0 acre (0.4 ha) (Walsberg 1977).

FOOD HABITS: Eats small insects and berries, including mistletoe, juniper, elderberry, *Rhus,* and others. Crops of mistletoe a staple for species; reported to defend fruiting mistletoe against nearly all other species that use it (Walsberg 1977). Captures insects in air; picks berries from stems, either by clinging to clusters or hovering about them.

OTHER:

REFERENCES: Grinnell and Storer 1924, Rand and Rand 1943, Bent 1950, Walsberg 1977.



Loggerhead Shrike

B150 (*Lanius ludovicianus*)

STATUS: No official listed status; on the 1978 Audubon Society Blue List, but apparently not because of problems in the western Sierra Nevada. Fairly common resident at low elevations.

DISTRIBUTION/HABITAT: Breeds in blue oak savannahs, digger pine-oak woodlands, and chaparral types; prefers stands with low percent canopy cover.

SPECIAL HABITAT REQUIREMENTS: Shrubs/grass-forbs.

BREEDING: Breeds from late February to mid-June, with peak from late March to early May. Nests in variety of trees and shrubs, with stable supporting branches and screen of overhanging cover. Nest height ranges from 2 to 30 ft (0.6 to 9.1 m). Clutch size from 5 to 7, with mean of 6.

TERRITORY/HOME RANGE: Territory and home range the same, radius of 1300 to 1950 ft (400 to 595 m) in San Joaquin Valley (Miller 1931). Maintains territory year-round. A 'headquarters' area more vigorously defended, including good lookout perches, feeding facilities, and suitable shrub or tree cover for shelter at night.

FOOD HABITS: Indiscriminate carnivore, captures insects and other invertebrates, small reptiles, birds, and mammals. Dives to ground from elevated perch, and sometimes hawks for aerial insects. Frequently impales prey on thorns or barbed wire.

OTHER:

REFERENCES: Miller 1931, Linsdale 1938, Bent 1950.

Starling

B151 *(Sturnus vulgaris)*

STATUS: No official listed status. Introduced from Europe into New York more than 100 years ago; rapidly spread across continent. Reported as rare in California as recently as 30 years ago (Grinnell and Miller 1944); today a serious agricultural pest. In the Sierra Nevada, rare and generally confined to low elevations.

DISTRIBUTION/HABITAT: Breeds in low elevation riparian deciduous, blue oak savannahs, and digger pine-oak woodlands. Prefers stands with low percent canopy cover. More common in vicinity of human habitations. In nonbreeding periods, found in same habitats but usually forms flocks, sometimes enormous ones.

SPECIAL HABITAT REQUIREMENTS: Nest cavities; openings or open terrain.

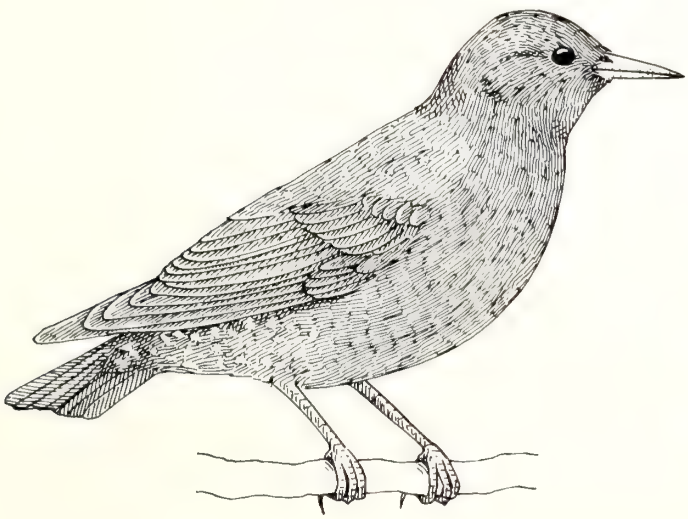
BREEDING: Breeds from early April to mid-June, with peak from mid-May to mid-June; often double-brooded. Nests in almost any suitably-sized natural or artificial cavity; in absence of cavities, known to nest on ground. Nest height ranges from 2 to 60 ft (0.6 to 18 m), usually from 10 to 25 ft (3.1 to 7.6 m). Clutch size from 3 to 6, with mean of 4.5.

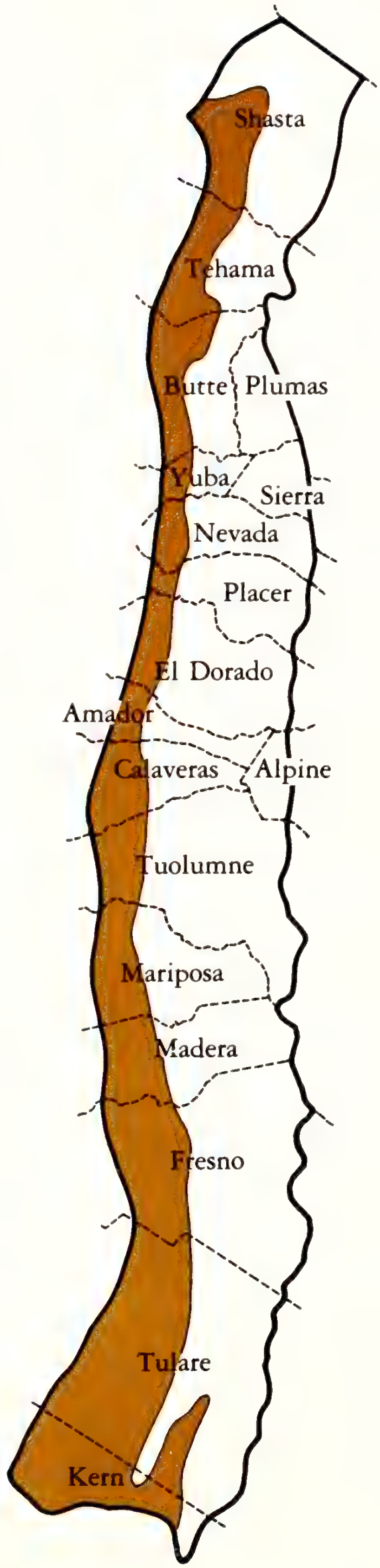
TERRITORY/HOME RANGE: Travels great distances in search of food; no data on home range (Hamilton and Gilbert 1969). In New York, defended only area immediately around nest but ranged up to 0.75 mi (1.2 km) from nest (Kessel 1957).

FOOD HABITS: Omnivorous, taking grain, hay, weed seeds, insects, earthworms, waste food, and other foods. Feeds in pastures, tilled soil, trees, garbage dumps, lawns, and other places. Probes in soil, gleans, hawks insects, and captures aerial insects in swallow-like flight.

OTHER: Considered a serious competitor for nest cavities with other cavity nesting species.

REFERENCES: Kessel 1957, Howard 1959, Planck 1967.





Hutton's Vireo

B152 *(Vireo huttoni)*

STATUS: No official listed status. Fairly common permanent resident in foothills.

DISTRIBUTION/HABITAT: Breeds in blue oak savannahs, digger pine-oak woodlands, and low elevation riparian deciduous areas. Prefers stands with low percent canopy coverage. Found almost exclusively in live oaks most of year, but in late summer and fall, moves upslope into ponderosa pine and black oak woodland types.

SPECIAL HABITAT REQUIREMENTS: Live oaks; trees/shrubs.

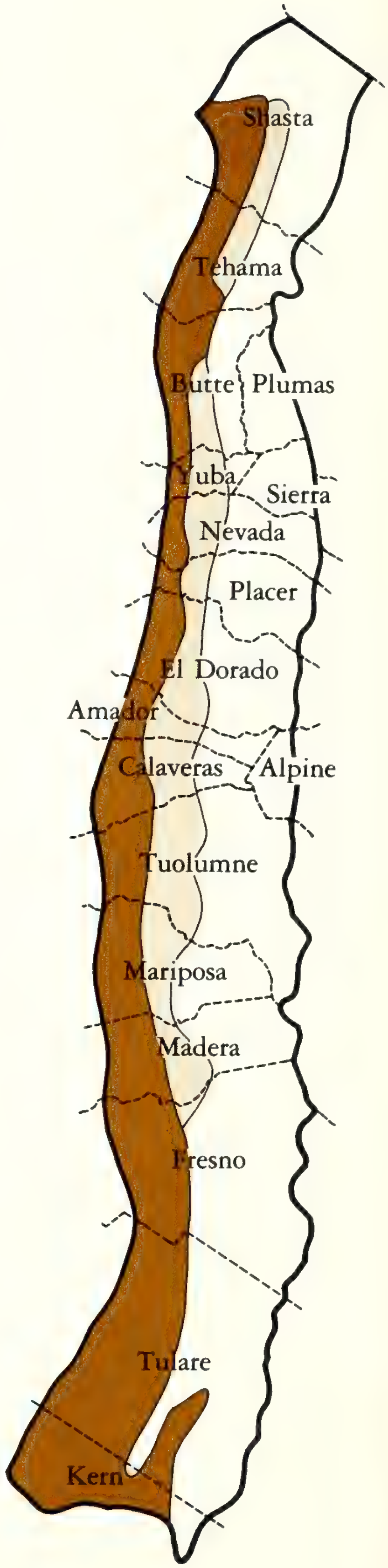
BREEDING: Breeds from early March to late June, with peak from late April to early June. Nests usually well concealed in tall live oak, supported by forked twig; also nests in bay laurel, willow, or pine. Nest height ranges from 7 to 25 ft (2.1 to 7.6 m). Clutch size from 3 to 5, with mean of 4.

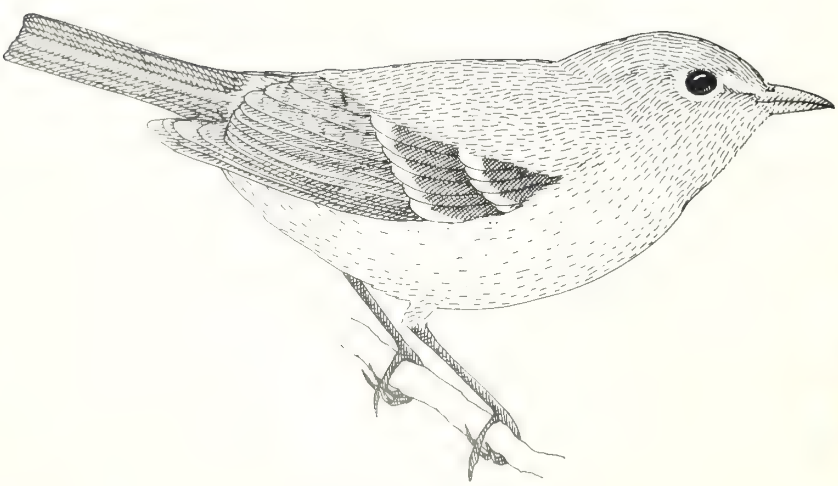
TERRITORY/HOME RANGE: No data on home range or territory size. In Sonoma County, Van Fleet (1919) reported breeding density of 100 pairs/mi^2 (39 pairs/km^2).

FOOD HABITS: Eats mostly insects and spiders, also some fruits and berries. Gleans food from foliage and small twigs in trees; also hawks aerial insects.

OTHER:

REFERENCES: Grinnell and Miller 1944, Bent 1950, Sumner and Dixon 1953.





Bell's Vireo

B153 *(Vireo bellii)*

STATUS: No official listed status; on the 1978 Audubon Society Blue List. Considered by some to be extinct in the Sierra Nevada and Central Valley habitats formerly occupied (R. Stallcup, pers. commun.).

DISTRIBUTION/HABITAT: Formerly nested in dense, low elevation riparian thickets in spring and summer.

SPECIAL HABITAT REQUIREMENTS: Dense riparian thickets.

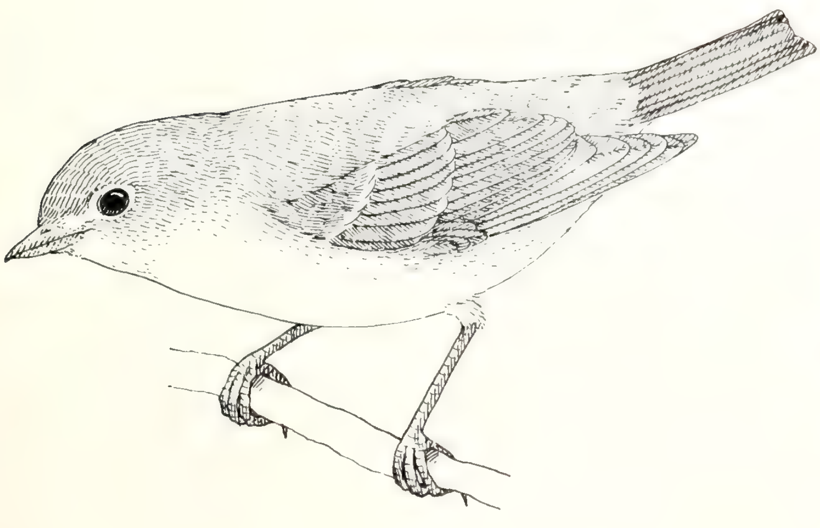
BREEDING: Breeds from early April to early July, with peak from mid-May to early June. Nests usually suspended from scrubby trees or low bushes—willow, *Baccharis,* blackberry, live oaks, poison oak, and others, always within 3 ft (0.9 m) of ground. Mean clutch size of 4.

TERRITORY/HOME RANGE: In southern Indiana, home range covers 2 to 3 acres (0.8 to 1.2 ha) per pair (Nolan 1960). Barlow *et al.* (1970) reported a breeding density of one pair per 2 acres (0.8 ha) in an Arizona mesquite thicket.

FOOD HABITS: Eats mostly insects, some fruits. Gleans from twigs and foliage, usually within 3 ft (0.9 m) of ground, primarily in riparian habitats, but some in live oak.

OTHER: Formerly a common summer resident at low elevations in the Sierra Nevada, even up to 4000 ft (1220 m) along the Tuolumne and Merced Rivers (Grinnell and Storer 1924). Apparently extinct in the western Sierra Nevada, partly because of reduction in suitable streamside vegetation and partly because of cowbird nest parasitism.

REFERENCES: Grinnell and Miller 1944, Bent 1950, Nolan 1960.



Solitary Vireo

B154 *(Vireo solitarius)*

STATUS: No official listed status. Fairly common migrant and summer resident in suitable habitat.

DISTRIBUTION/HABITAT: Breeds in ponderosa pine, black oak woodland, riparian deciduous, and mixed-conifer types; prefers drier sites with substantial shrub layer and low to intermediate percent canopy cover. Spring migrants pass through lower elevation oak and pine/oak types; in late summer and early fall usually moves upslope as high as lodgepole pine forests.

SPECIAL HABITAT REQUIREMENTS:

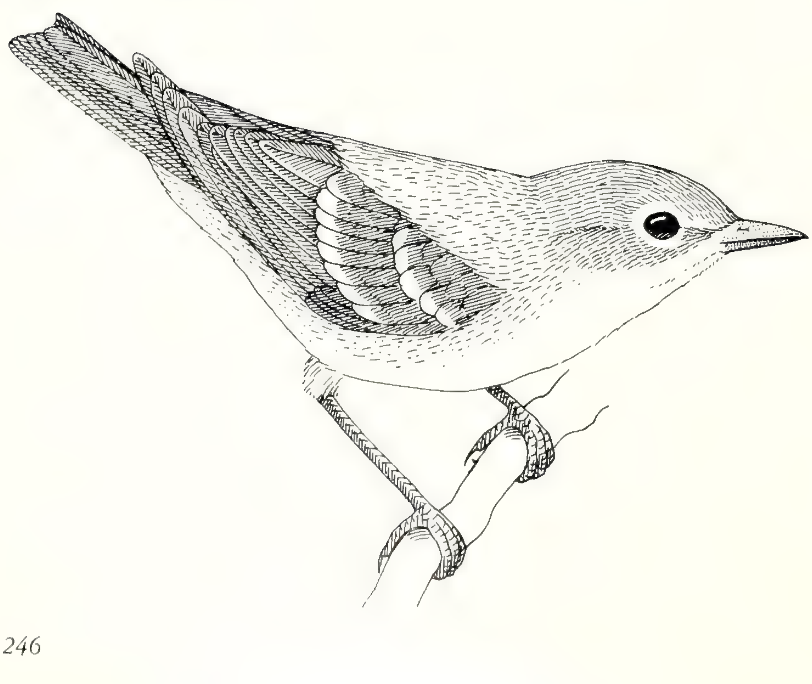
BREEDING: Breeds from late April to mid-July, with peak from late May to early July. Nests usually in low, dense foliage of shrubs and trees and typically shaded. Nest height ranges from 5 to 20 ft (1.5 to 6.1 m). Clutch size from 3 to 5, with mean of 4.

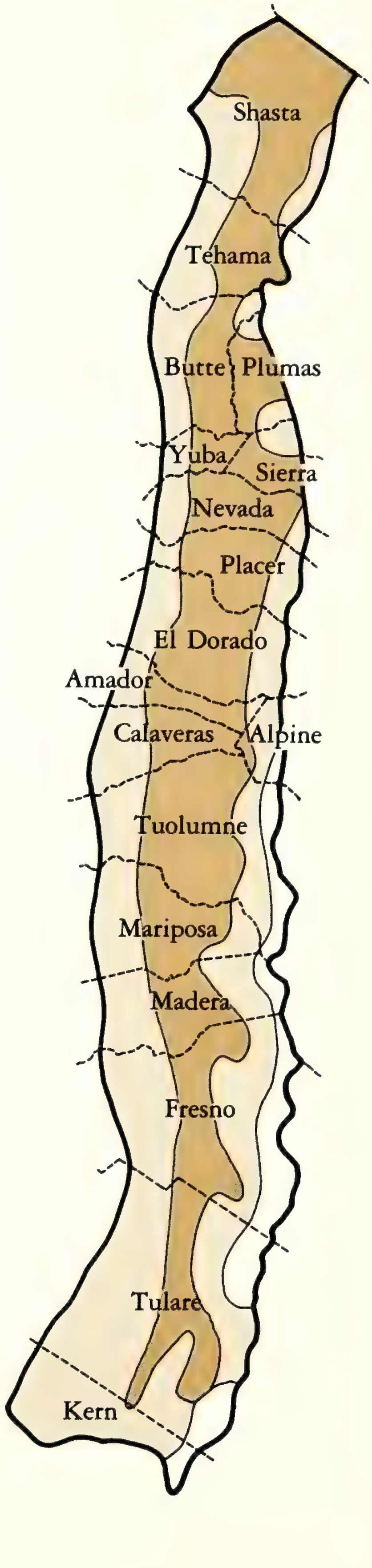
TERRITORY/HOME RANGE: No data available on home range. In an Arizona piñon-juniper-ponderosa pine ecotone, territory size averaged 4.2 acres (1.7 ha) (Laudenslayer and Balda 1976).

FOOD HABITS: Feeds mostly on insects, also eats some leaf galls and seeds. Gleans food from foliage of trees.

OTHER: Population declined in recent years, at least in part as result of increased nest parasitism by brown-headed cowbirds (Gaines 1977).

REFERENCES: Grinnell and Storer 1924, Grinnell and Miller 1944, Bent 1950.





Warbling Vireo

B155 *(Vireo gilvus)*

STATUS: No official listed status; on the 1978 Audubon Society Blue List. Common spring migrant and summer resident in most vegetation types.

DISTRIBUTION/HABITAT: Breeds in wooded sites from low elevation riparian deciduous up to red fir forests. Prefers areas with tall trees, a substantial shrub layer, and low to intermediate percent canopy cover. Generally gone from the western Sierra Nevada by late summer.

SPECIAL HABITAT REQUIREMENTS:

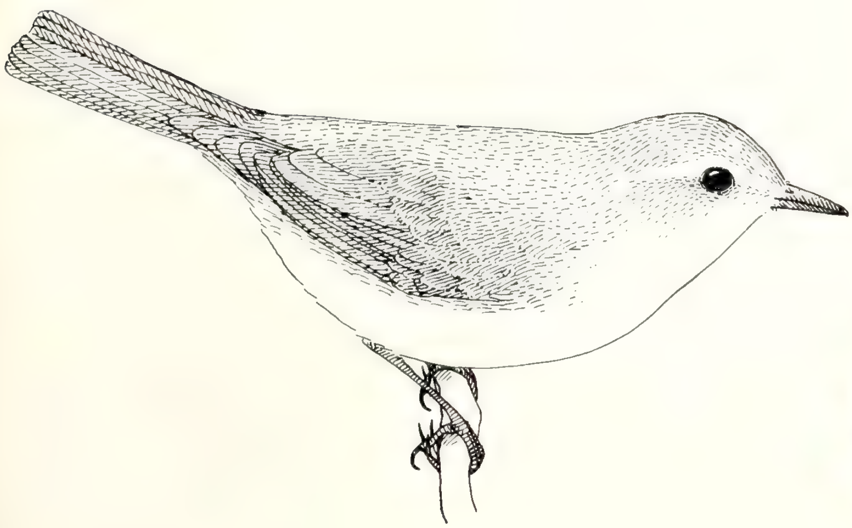
BREEDING: Breeds from late April to late July, with peak from late May to mid-July. Nests attached at upper rim, with cup hanging down, to terminal foliage of branches in tall trees (deciduous preferred). Nest height ranges from 4 to 40 ft (1.2 to 12 m) up, usually above 8 ft (2.4 m). Clutch size from 3 to 5, with mean of 4.

TERRITORY/HOME RANGE: No data on territory size. In Idaho, Rust (1920) reported a home range of 120 ft (37 m) radius around nest.

FOOD HABITS: Eats mostly insects and spiders, also some fruits and seeds. Gleans food from foliage of deciduous and coniferous trees, sometimes hovering to do so; also hawks for airborne insects.

OTHER: By far the most common breeding vireo in the Sierra Nevada. Gaines (1977) has nonetheless noted a significant decline in numbers in the Yosemite Valley since the 1930's. Again, nest parasitism by the brown-headed cowbird thought to be a reason for the decline.

REFERENCES: Grinnell and Storer 1924, Grinnell and Miller 1944, Bent 1950.



Orange-crowned Warbler

B156 (*Vermivora celata*)

STATUS: No official listed status. Common spring and summer visitor in suitable habitat.

DISTRIBUTION/HABITAT: Breeds at lower elevations from blue oak savannah to chaparral, and in low elevation riparian deciduous areas. Prefers sites with considerable shrub cover.

SPECIAL HABITAT REQUIREMENTS: Dense shrubs for nesting.

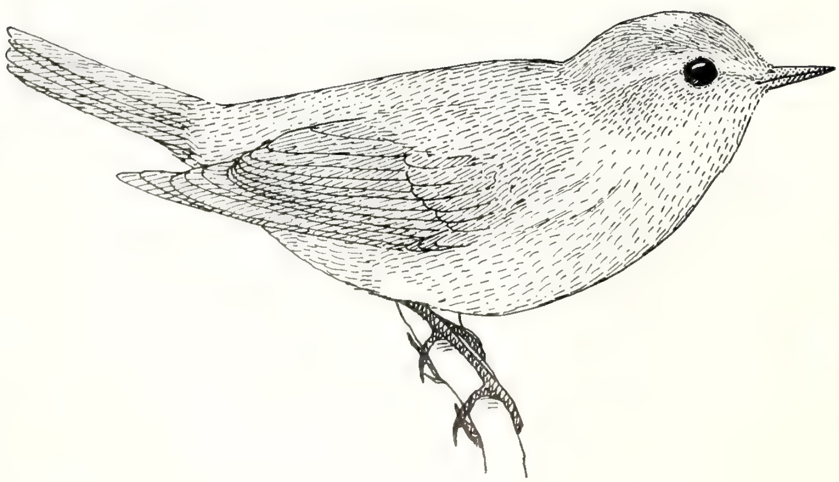
BREEDING: Breeds from late April to early June, with peak in mid-May. Nests on ground or occasionally in low, dense bushes. Nest height generally below 3 ft (1 m). Clutch size 3 to 6, with mean of 4.

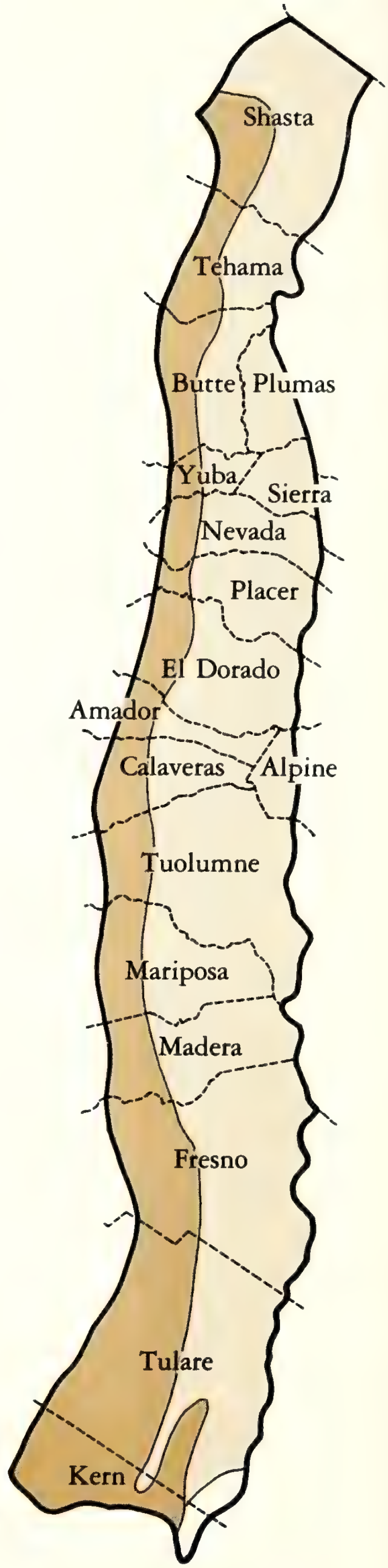
TERRITORY/HOME RANGE: Only meager data available. In California coastal chaparral, Mans (1961) reported a male patrolled an area of about 5 acres (2 ha).

FOOD HABITS: Feeds mostly on insects, also some seeds and fruit. Gleans insects from foliage in shrubs and small trees at heights ranging from 5 to 30 ft (1.5 to 9.1 m).

OTHER: Although Grinnell and Miller (1944) cite Transition Zone breeding localities, no confirmed nesting records at elevations above 1600 ft (490 m). Known to nest only in chaparral and shrubby oak woodlands of foothills. Upslope or southward movement to mixed-conifer belt begins as early as June. In late summer and early fall, relatively common in high elevation coniferous forests, but most belong to populations from distant localities that migrate through the Sierra Nevada.

REFERENCES: Griscom and Sprunt 1957, Gaines 1977.





Nashville Warbler

B157 *(Vermivora ruficapilla)*

STATUS: No official listed status. Fairly common spring and summer resident.

DISTRIBUTION/HABITAT: Breeds in mid-elevation conifer types, from ponderosa pine to mixed-conifer forests, in black oak woodland and, to some extent, in riparian deciduous. Prefers timbered areas with low percentage canopy cover, though brush-covered sites with no trees also used.

SPECIAL HABITAT REQUIREMENTS: Trees/shrubs.

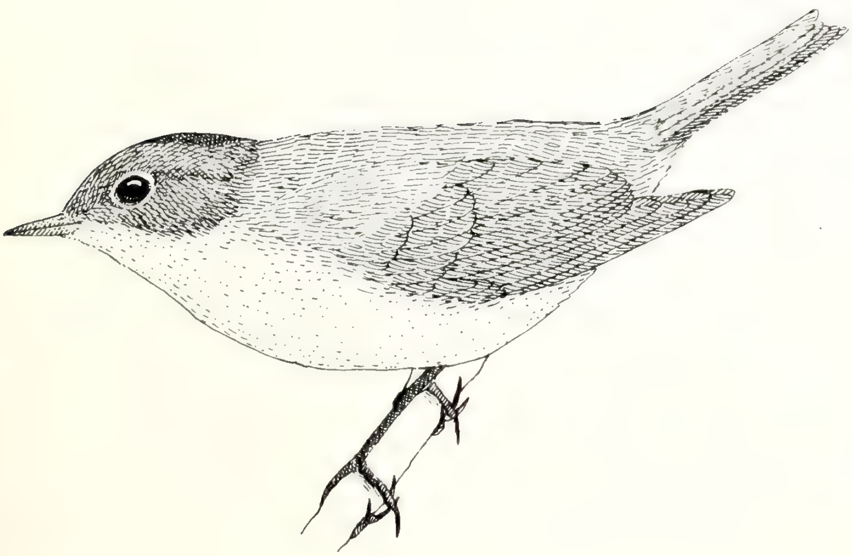
BREEDING: Breeds from mid-May to late July, with peak in mid-June. Nests on ground in areas with dense shrubs and sparse trees. Clutch size from 3 to 5, with mean of 4.

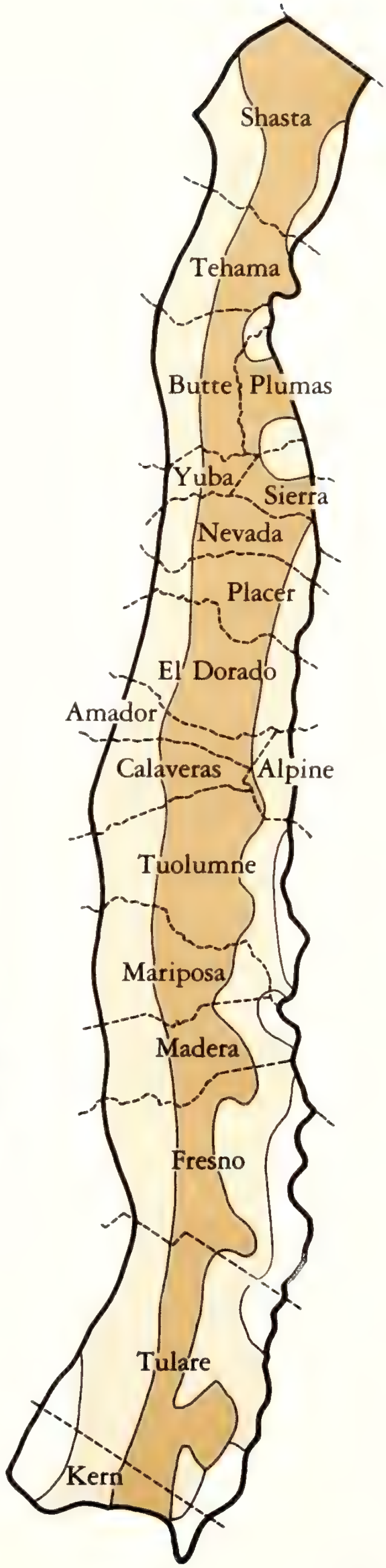
TERRITORY/HOME RANGE: No information on home range. In a deciduous/coniferous forest in Ontario, Lawrence (1948) reported mean territory size of about 0.5 acre (0.2 ha).

FOOD HABITS: Feeds almost entirely on insects gleaned from foliage or taken from air by hawking. Feeds in low shrubs and up into higher canopy.

OTHER: Late season wanderers recorded as high as 11,000 ft (3350 m) in Yosemite National Park. Nests frequently parasitized by brown-headed cowbirds.

REFERENCES: Lawrence 1948, Griscom and Sprunt 1957, Johnson 1976.





Yellow Warbler

B158 *(Dendroica petechia)*

STATUS: No official listed status; on the Audubon Society Blue List for 1978. Fairly common spring and summer resident in the western Sierran zone.

DISTRIBUTION/HABITAT: Breeds in riparian deciduous, lakeshore, or wet, shrubby meadows from blue oak savannahs up to mixed-conifer forest.

SPECIAL HABITAT REQUIREMENTS: Dense shrubs; usually nearby water for nesting.

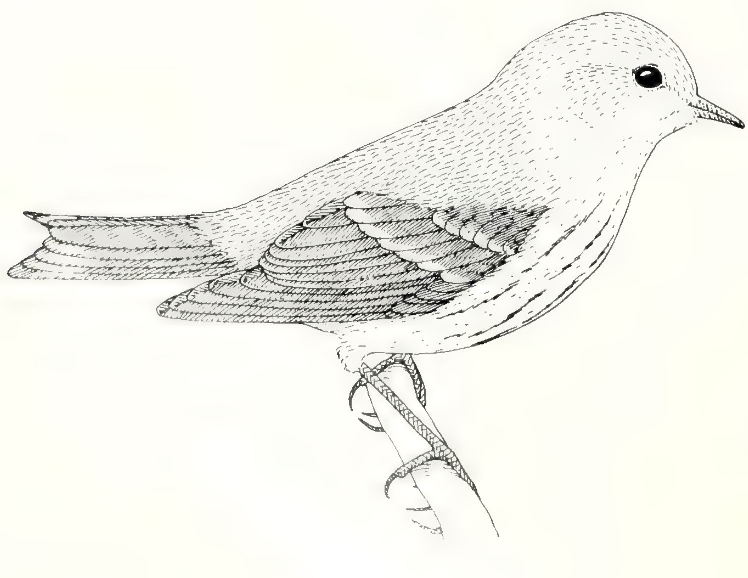
BREEDING: Breeds from mid-April to mid-July, with peak from early to late May. Nests in low bushes, usually in riparian sites but sometimes in open, moist forests. Nest height varies from 2 to 10 ft (0.6 to 3.1 m). Clutch size from 3 to 5, with 3 or 4 most frequent.

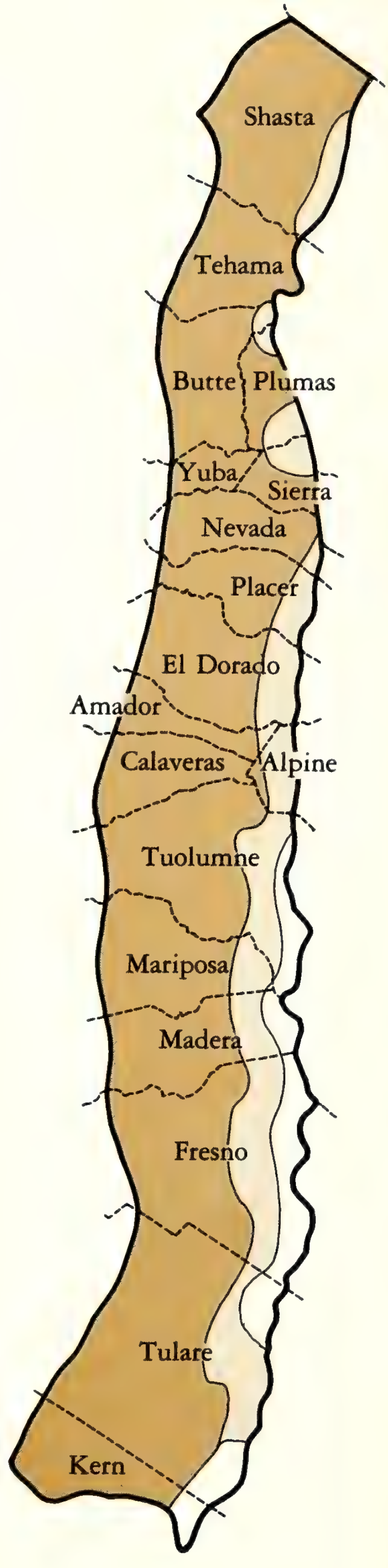
TERRITORY/HOME RANGE: In Illinois, breeding territory sizes reported in riparian woodland as ranging from 0.15 to 0.94 acre (0.06 to 0.4 ha), with mean of 0.42 acre (0.17 ha) (Brewer 1955); in riparian cover in Utah as ranging from 0.13 to 0.65 acre (0.05 to 0.26 ha) (Frydendall 1967); and on small islands in Minnesota to be as small as 0.08 acre (0.03 ha) (Beer *et al.* 1956). Feeds mostly outside territory, usually to distances of 400 to 600 ft (120 to 185 m) and some birds regularly to as far as 1600 ft (490 m) (Kendeigh 1941a).

FOOD HABITS: Diet consists almost entirely of insects, with some spiders. Gleans food from foliage of coniferous and deciduous trees.

OTHER: Although normally associated with low-elevation, streamside forests, frequently observed foraging in mid-elevation coniferous forests during postnesting season (Hebard 1961, Beedy 1975).

REFERENCES: Schranz 1943, Griscom and Sprunt 1957.





Yellow-rumped Warbler

B159 *(Dendroica coronata)*

STATUS: No official listed status. Abundant resident in the State; spring, summer, and fall visitor to middle and high elevations of the Sierra Nevada forests.

DISTRIBUTION/HABITAT: Widespread; found at lower elevations in all seasons, except summer. Breeds from ponderosa pine and black oak types up to lodgepole pine forests; prefers timbered sites of low percentage canopy cover and forest edges, as around meadows or lakes.

SPECIAL HABITAT REQUIREMENTS:

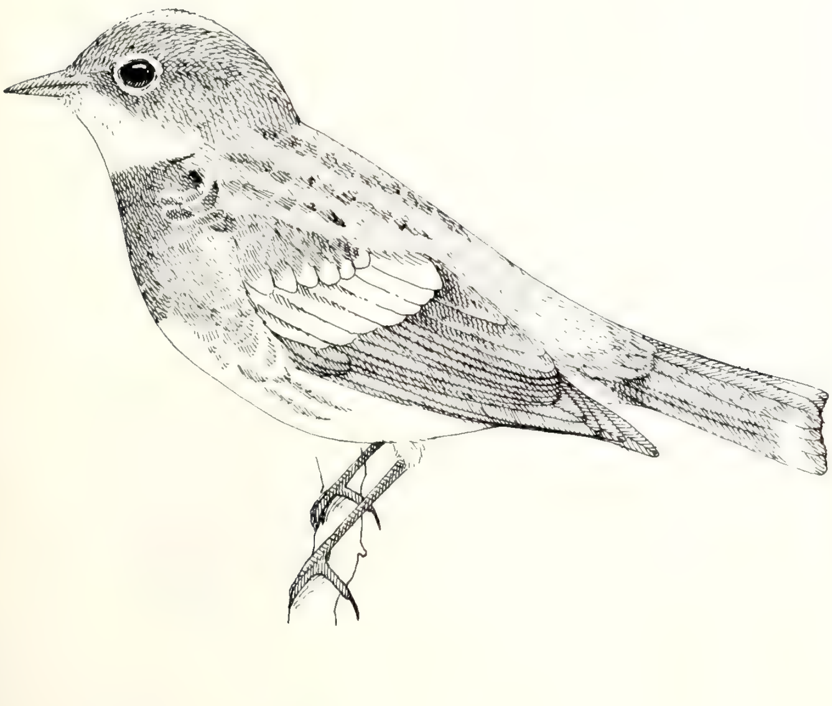
BREEDING: Breeds from mid-May to late July, with peak from middle to late June. Nests in conifers, in deciduous trees, or in shrubs, from 3 to 100 ft (0.9 to 3.1 m) up. Clutch size from 3 to 5, with a mean of 4.

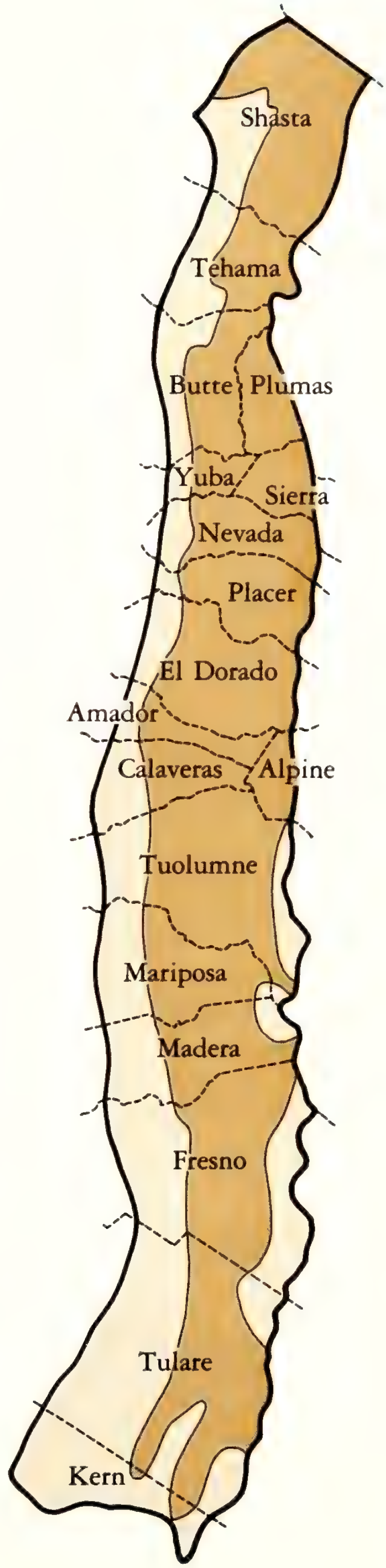
TERRITORY/HOME RANGE: No information on home range or territory size. Beedy (1975) reported a density of 40.4 birds per 100 acres (40 ha) in mixed-conifer forest in the Sierra Nevada.

FOOD HABITS: Eats 85 percent insects and spiders and 15 percent vegetable matter. Hawks for flying insects, gleans insects from foliage, and searches for food on ground.

OTHER:

REFERENCES: Griscom and Sprunt 1957, Gaines 1977.





Black-throated Gray Warbler

B160 *(Dendroica nigrescens)*

STATUS: No official listed status. Uncommon to fairly common spring and summer visitor to oak-conifer belt.

DISTRIBUTION/HABITAT: Breeds in all oak types and in ponderosa pine forests, if some oaks present. Exhibits some preference for sites with low percentage canopy coverage.

SPECIAL HABITAT REQUIREMENTS: Oaks; trees/shrubs.

BREEDING: Breeds from early May to early July, with peak from mid-May to mid-June. Nests on horizontal branches from ground level up to 50 ft (15 m), but usually from 3 to 10 ft (0.9 to 3.1 m) up. Clutch size from 3 to 5, with mean of 4.

TERRITORY/HOME RANGE: No information available.

FOOD HABITS: Insects generally comprise the diet, with oak worms and caterpillars favored. Hawks flying insects and gleans insects from foliage from low to moderate heights in tree canopy.

OTHER Rarely observed at elevations greater than 6000 ft (1830 m); in some regions largely restricted to golden oak habitat (Grinnell and Storer 1924).

REFERENCES: Grinnell and Storer 1924, Griscom and Sprunt 1957.

Townsend's Warbler

B161 *(Dendroica townsendi)*

STATUS: No official listed status. Uncommon to fairly common fall migrant; rarely observed in the Sierra Nevada during spring migration.

DISTRIBUTION/HABITAT: Frequents timbered stands from black oak woodland up to lodgepole pine forests; prefers low to intermediate canopy cover.

SPECIAL HABITAT REQUIREMENTS:

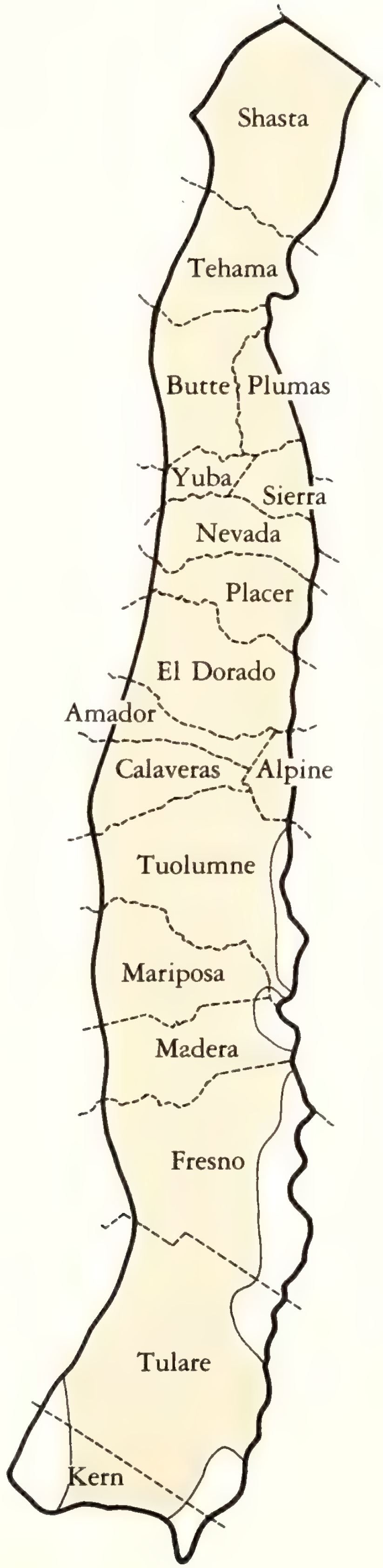
BREEDING: Does not breed in the western Sierra Nevada.

TERRITORY/HOME RANGE: None established in the western Sierran zone.

FOOD HABITS: Food consists of insects obtained by gleaning foliage of dense conifers.

OTHER: Fall migrants found primarily at higher elevations, usually associated with migratory flocks of yellow-rumped warblers.

REFERENCES: Griscom and Sprunt 1957, Gaines 1977.



Hermit Warbler

B162 *(Dendroica occidentalis)*

STATUS: No official listed status. Fairly common to common spring and/or summer resident in mid-elevation conifer forests.

DISTRIBUTION/HABITAT: Breeds in ponderosa pine, black oak woodlands, and mixed-conifer forests, prefers stands with large trees and low to intermediate percentage canopy cover. By July and August, after breeding season, spreads upslope through red fir forests.

SPECIAL HABITAT REQUIREMENTS: Large trees.

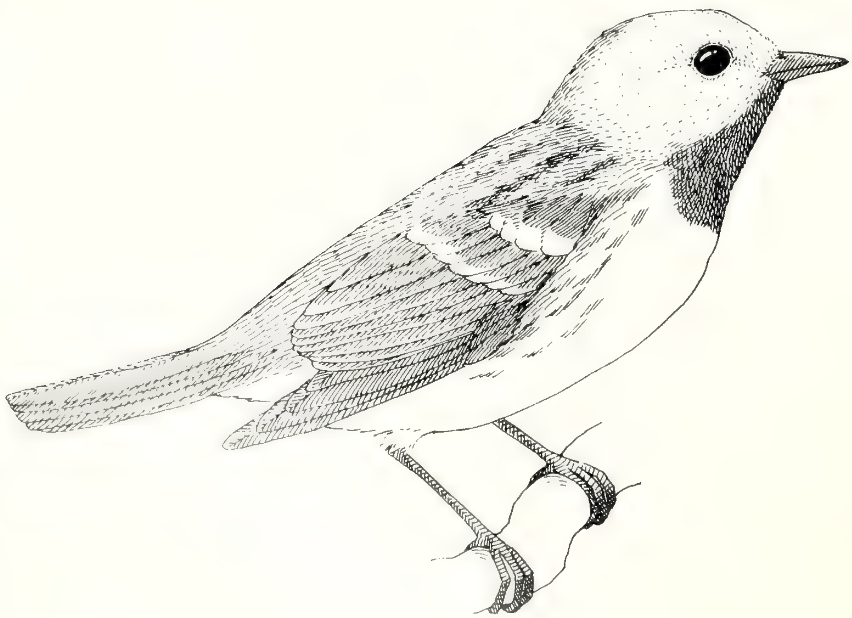
BREEDING: Breeds from late April to late June, with peak from early to mid-June. Nests on horizontal branches in relatively tall conifers, from 2 to 50 ft (0.6 to 15 m) above ground. Clutch size from 3 to 5, with mean of 4.

TERRITORY/HOME RANGE: No data on either. Breeding density in mixed-conifer forest in the Sierra Nevada averaged 6.5 birds per 100 acres (40 ha) (Beedy 1975).

FOOD HABITS: Insects and spiders comprise the diet, with aerial insects hawked and other prey gleaned from foliage.

OTHER: When nesting in low to middle canopy, usually forage and sing in tallest trees. In general, the biology of species poorly known.

REFERENCES: Barlow 1899, Griscom and Sprunt 1957.



MacGillivray's Warbler

B163 *(Oporornis tolmiei)*

STATUS: No official listed status. Fairly common summer resident in suitable habitat.

DISTRIBUTION/HABITAT: Breeds in rather dense shrubbery and thickets, especially near water, from ponderosa pine zone upslope into mixed-conifer zone. Often found in mid-elevation wet meadows with low shrubs, such as willows. In postnesting period, small numbers travel through meadows and willow thickets to treeline.

SPECIAL HABITAT REQUIREMENTS: Dense shrubs near water for nesting.

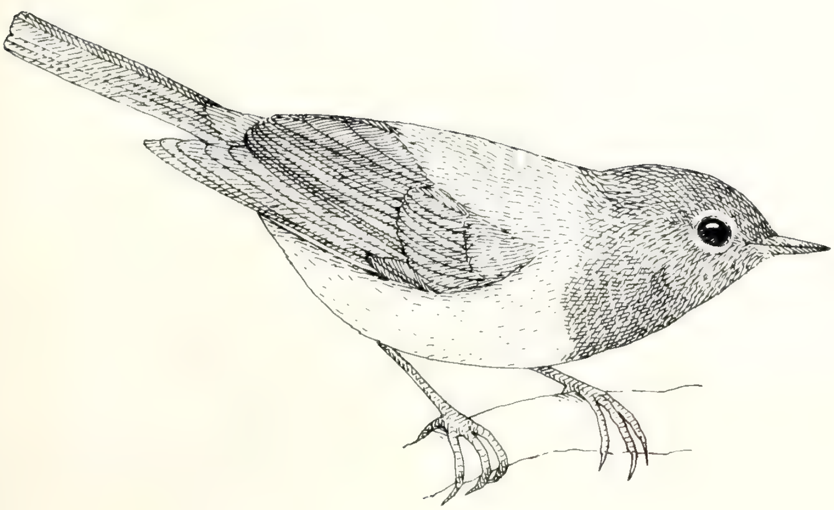
BREEDING: Breeds from early May to early July, with peak from early to mid-June. Nests usually from 2 to 6 ft (0.6 to 1.8 m) up in shrub in moist thicket, usually with tall herbs, grasses, or ferns. Clutch size from 3 to 6, with mean of 4.

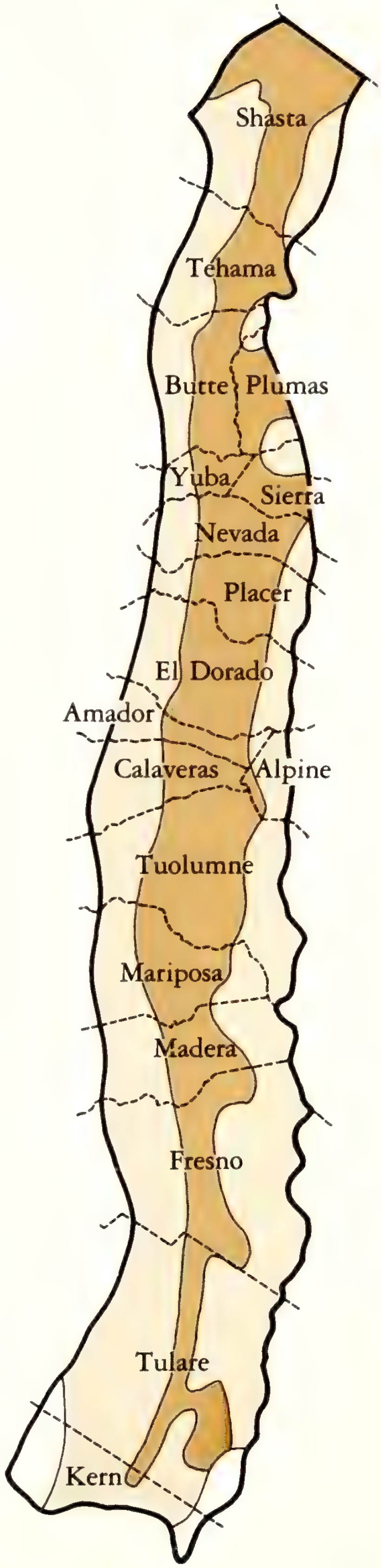
TERRITORY/HOME RANGE: No data on territory or home range sizes. Salt (1957) reported a mean density of 30 birds per 100 acres (40 ha) in aspen habitat in Wyoming.

FOOD HABITS: Insects, taken in dense shrubs or on ground, by foliage gleaning or probing in ground litter, make up majority of diet.

OTHER:

REFERENCES: Griscom and Sprunt 1957, Gaines 1977.





Common Yellowthroat

B164 *(Geothlypis trichas)*

STATUS: No official listed status. Fairly common summer resident, and spring and fall migrant in suitable areas. Substantially reduced in numbers in recent years because of drainage of essential aquatic habitat.

DISTRIBUTION/HABITAT: Breeds in marshy vegetation around ponds and along slow-moving streams or rivers, and in dense, mesic vegetation in wet meadows or in deciduous riparian habitat. Largely restricted to low elevations, observed on numerous occasions in Yosemite Valley and probably has nested there. Observed at elevations of 6000 ft (1830 m) in wet meadows in late summer.

SPECIAL HABITAT REQUIREMENTS: Marsh or dense shrubs near water for nesting.

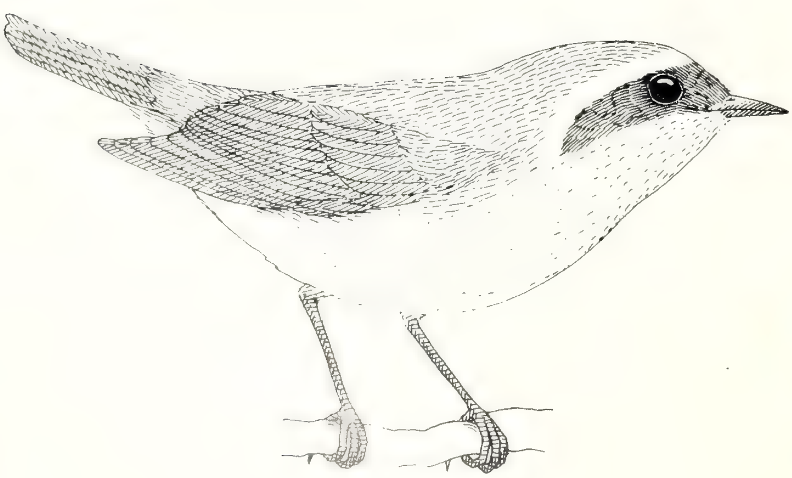
BREEDING: Breeds from early April to mid-July, with peak from mid-May to early June. Nests mostly on ground or supported by aquatic vegetation near or over water. Clutch size from 3 to 5, with mean of 4.6.

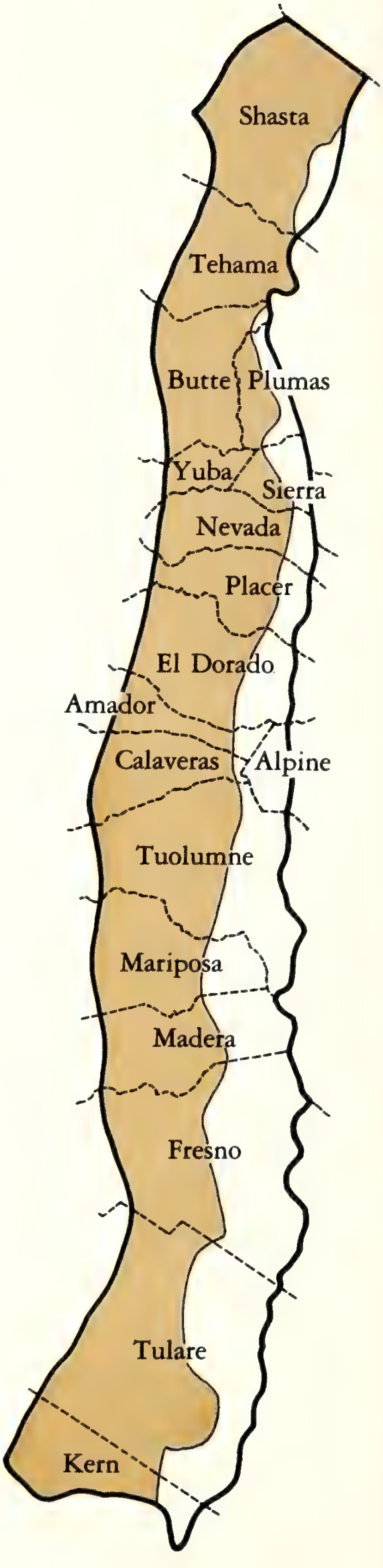
TERRITORY/HOME RANGE: Territory and home range probably the same. Reported sizes: average in marsh and riparian habitat in Michigan 1.3 acres (0.5 ha), with range from 0.8 to 1.8 acres (0.3 to 0.7 ha) (Stewart 1953); a mean of 0.6 acre (0.2 ha) in Illinois swamp, with range from 0.2 to 1.1 acres (0.1 to 0.5 ha) (Brewer 1955), and means of 0.7 acre (0.3 ha) in Minnesota and 1.7 acres (0.7 ha) in Michigan (Hofslund 1960).

FOOD HABITS: Large insects, especially caterpillars and other insect larvae, comprise majority of diet. Gleans from aquatic and marsh vegetation or foliage of shrubs in wet sites. Sometimes probes for food in ground.

OTHER:

REFERENCES: Stewart 1953, Griscom and Sprunt 1957.





Yellow-breasted Chat

B165 *(Icteria virens)*

STATUS: No official listed status; on the 1978 Audubon Society Blue List. Fairly common spring migrant and summer resident in suitable habitat.

DISTRIBUTION/HABITAT: Breeds in low elevation riparian deciduous habitats; breeding above 1000 ft (305 m) not confirmed. May not be a breeding species in western Sierran zone. Usually wanders upslope after breeding season, in late summer and early autumn. Recorded in riparian deciduous habitats as high as 4000 ft (1220 m).

SPECIAL HABITAT REQUIREMENTS: Dense riparian shrubs.

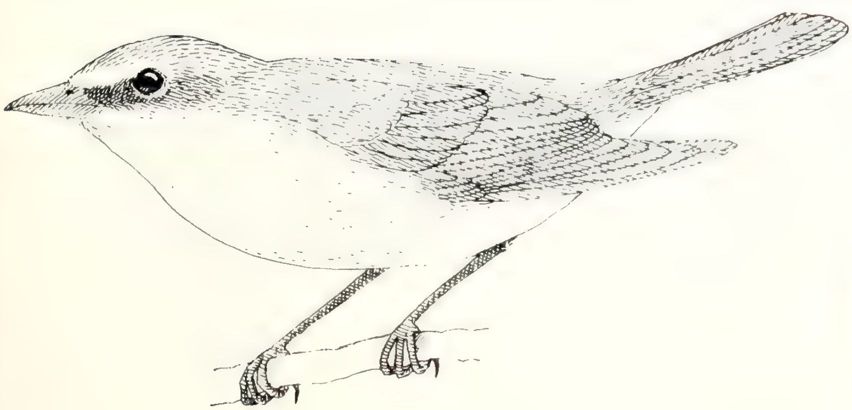
BREEDING: Breeds from early May to mid-July, with peak from early to mid-June. Nests usually at heights of 2 to 3 ft (0.6 to 0.9 m) in dense shrubs along stream courses. Clutch size from 3 to 6, with mean of 3.5.

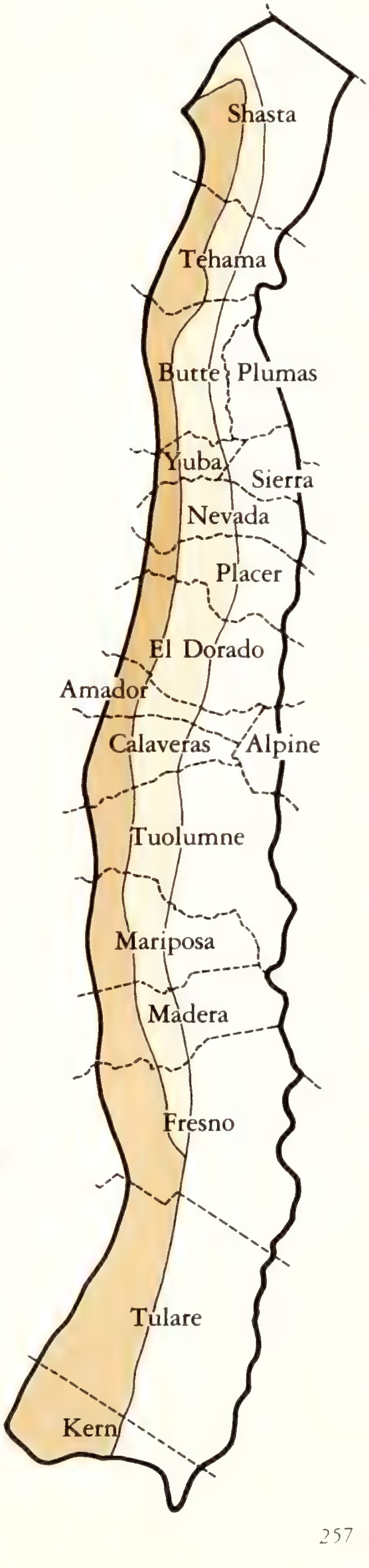
TERRITORY/HOME RANGE: In Illinois, Brewer (1955) reported home range sizes from 0.14 to 0.71 acre (0.06 to 0.3 ha), with mean of 0.33 acre (0.1 ha) in marsh and riparian habitat. In upland deciduous scrub habitat in Indiana, Thompson and Nolan (1973) found mean territory sizes ranging from a low of 2.8 acres (1.1 ha) in 1967 to high of 3.9 acres (1.6 ha) in 1970; pooled mean for all years: 3.1 acres (1.24 ha). In variously wooded and brushy habitat near a stream in Virginia, Dennis (1958) noted a range in territory size from 1.25 to 2.50 acres (0.5 to 1.0 ha).

FOOD HABITS: Insects make up bulk of diet; fruits also eaten. Most food obtained by gleaning foliage of shrubs and small trees.

OTHER: Numbers reduced in the Sierra Nevada through habitat destruction.

REFERENCES: Griscom and Sprunt 1957, Dennis 1958, Thompson and Nolan 1973.





Wilson's Warbler

B166 (*Wilsonia pusilla*)

STATUS: No official listed status. Common summer resident.

DISTRIBUTION/HABITAT: Breeds in riparian sites, around some lakeshore habitat, or in wet meadows in middle to high elevations. Also forages along forest edges and within dense coniferous forests during postnesting season (Beedy 1975).

SPECIAL HABITAT REQUIREMENTS: Dense shrubs near water for breeding.

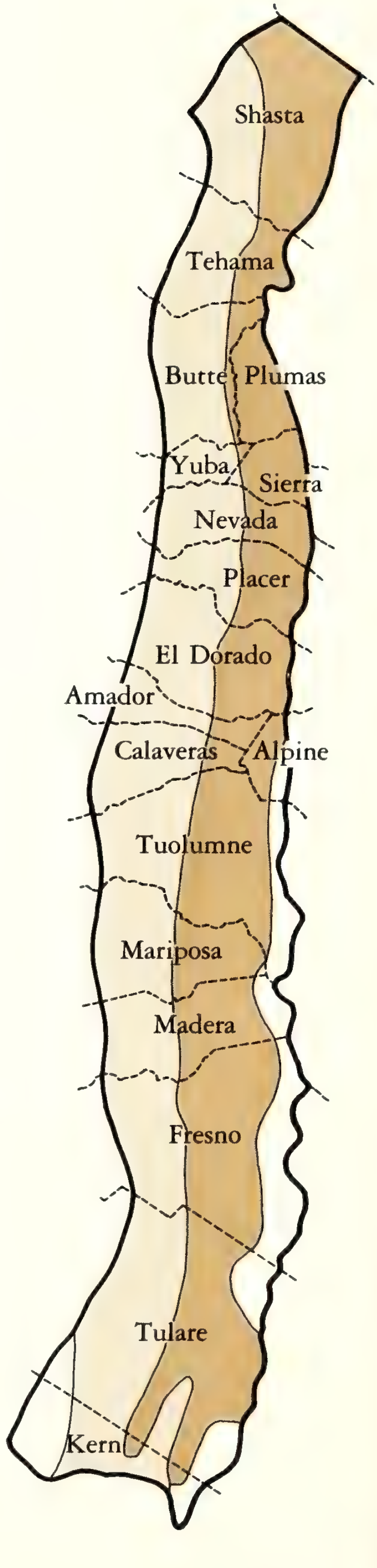
BREEDING: Breeds from late April to early July, with peak from mid-May to mid-July. Nests usually on ground among mosses and grasses, often at base of small tree or shrub, and typically located within dense shrubs. Clutch size from 4 to 6, with mean of 5.

TERRITORY/HOME RANGE: In a study in bay-laurel habitat in Marin County, Stewart (1973) reported that they ranged from 410 to 984 ft (125 to 300 m) from their nest. He reported territory sizes from 0.5 to 3.2 acres (0.2 to 1.3 ha), with mean of 1.2 acres (0.5 ha) in same area.

FOOD HABITS: Insects make up 90 percent of diet, seeds and berries 10 percent. Gleans foliage near ground and hawks for flying insects.

OTHER:

REFERENCES: Harrison 1951, Griscom and Sprunt 1957, Stewart 1973.



House Sparrow

B167 *(Passer domesticus)*

STATUS: No official listed status. Common permanent resident.

DISTRIBUTION/HABITAT: Breeds in all types and successional stages from annual grasslands up to ponderosa pine and black oak woodlands; established only in areas inhabited by humans, especially where livestock occur.

SPECIAL HABITAT REQUIREMENTS: Human habitations.

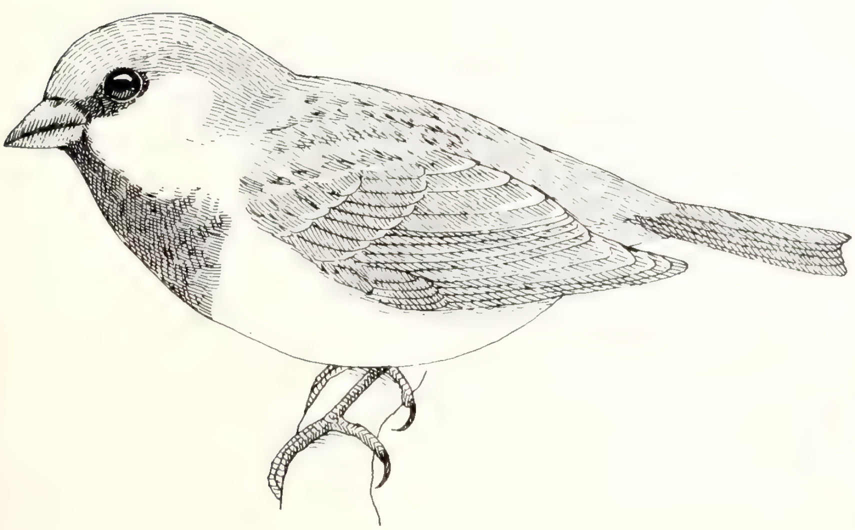
BREEDING: Breeds from early March to early August, with peak from early May to late June. Highly versatile in selection of nest sites, which may be almost any cavity, crevice or dense branchwork; often in buildings, under eaves, or in decorative grillwork. Nest height ranges from 5 to 50 ft (1.5 to 15 m). Three to 7 eggs per clutch, with mode of 5.

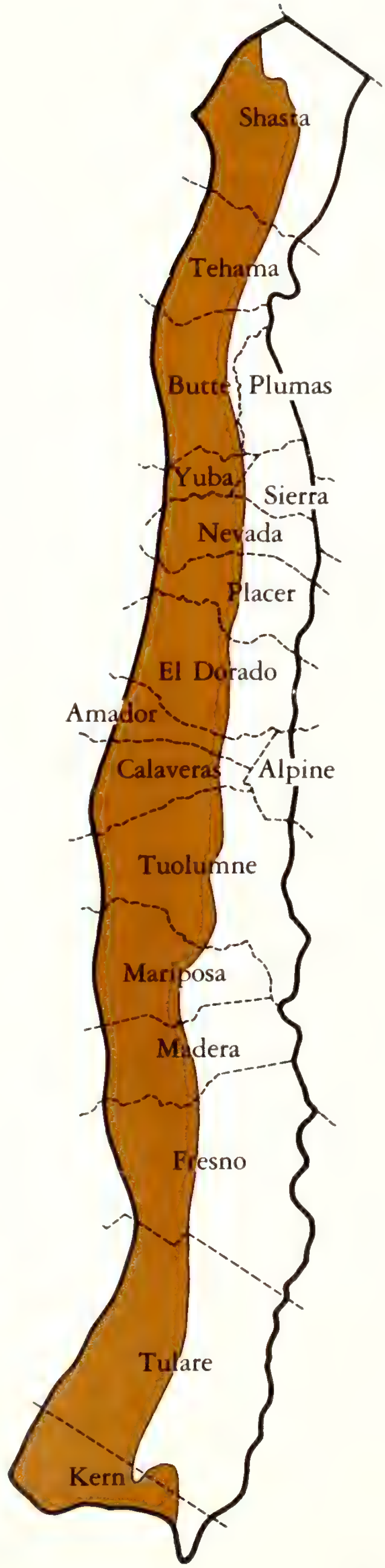
TERRITORY/HOME RANGE: In Illinois and Wisconsin, Owen (1957) reported that an area ranging in diameter from 1.5 to 20 ft (0.5 to 6.1 m) around the nest defended. Average area 158 ft^2 (14.7 m^2). Nonbreeders reported traveling up to 2 mi (3.2 km) from roost sites to foraging sites in Oklahoma (North 1973) and New York (Weaver 1939).

FOOD HABITS: Adults eat mostly seeds and other vegetable matter; nestlings fed insects and seeds. Gleans most of food from ground, also from foliage. The common "garbage" bird of city streets.

OTHER: Introduced into Eastern United States from Europe during middle of last century; successfully spread throughout the country. More abundant during pre-automobile period, usually foraged in horse manure. Aggressive; frequently evicts other cavity nesting species from nest sites.

REFERENCES: Summers-Smith 1963, Kendeigh 1973, North 1973.





Western Meadowlark

B168 *(Sturnella neglecta)*

STATUS: No official listed status. Common resident at low elevations; late summer and fall transient at higher elevations.

DISTRIBUTION/HABITAT: Breeds in grasslands and pastureland from annual grassland up to chaparral zone, with or without moderate shrub cover, and generally in drier sites. Some upslope movement in late summer and fall.

SPECIAL HABITAT REQUIREMENTS: Open terrain.

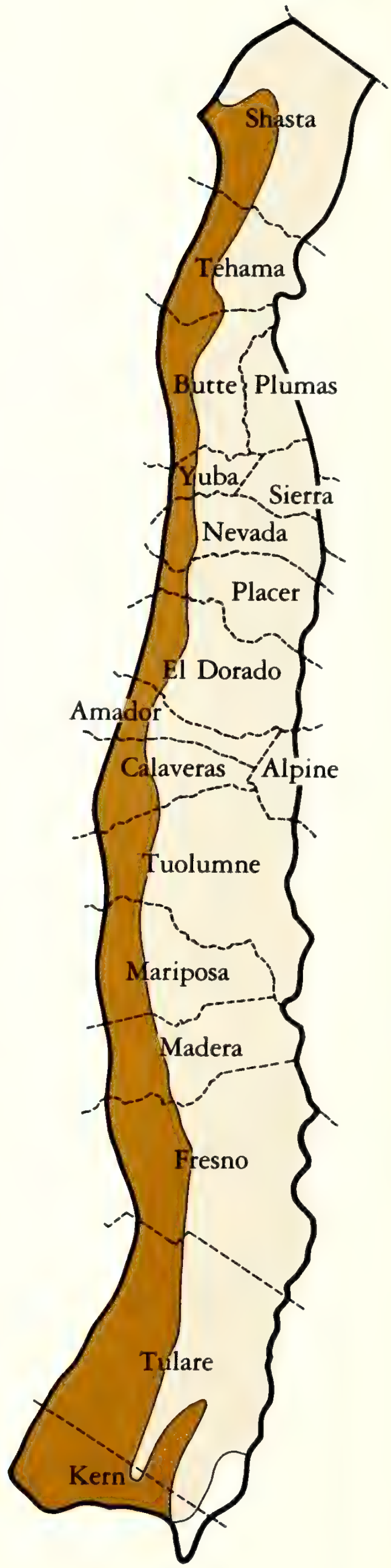
BREEDING: Breeds from early February to late July, with peak from late April to late June. Nests in depression on ground, among grasses or other low vegetation. Clutch size from 3 to 7, with mode of 5.

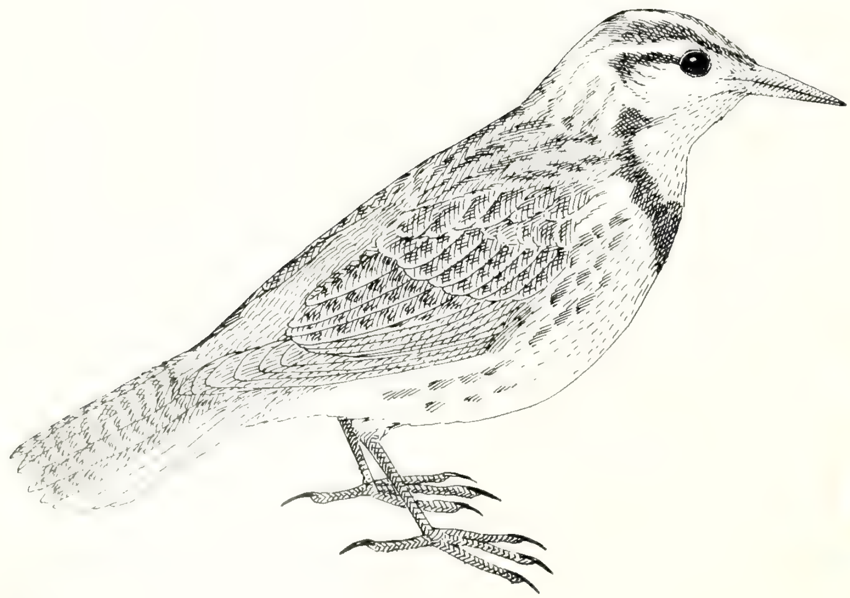
TERRITORY/HOME RANGE: Home range same as territory. In Wisconsin, breeding territories ranged from 3 to 15 acres (1.2 to 6.1 ha), with mean of about 7.5 acres (3 ha) (Lanyon 1956).

FOOD HABITS: Insects and seeds, gleaned from grasses and live or dead annuals, or from the ground, make up the majority of the diet. Turns over clods and digs in soft earth.

OTHER:

REFERENCES: Bryant 1914, Grinnell and Miller 1944, Lanyon 1957.





Yellow-headed Blackbird

B169 *(Xanthocephalus xanthocephalus)*

STATUS: No official listed status. Rare spring and fall migrant.

DISTRIBUTION/HABITAT: Prefers large, marshy areas with water of considerable depth and patches of open water. Forages in moist, open areas and in marshes; requires marshes only during breeding season.

SPECIAL HABITAT REQUIREMENTS: Marshes for nesting; open terrain.

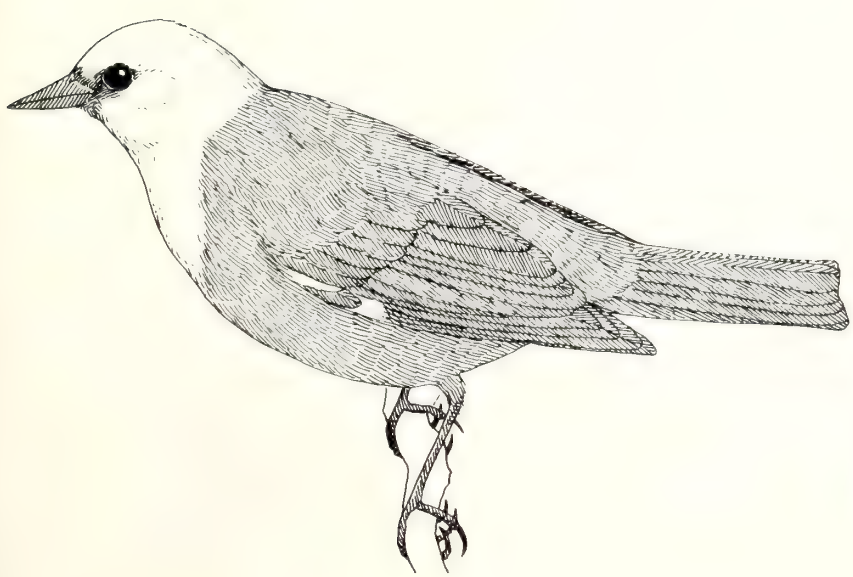
BREEDING: Possibly breeds in the western Sierran zone at low elevations from mid-April to late July, with peak from late May to mid-July. Nests in emergent vegetation, usually cattails or bulrush, from 0.5 to 3 ft (0.2 to 0.9 m) above water, usually near edge of vegetation farthest from shore. Clutch size from 2 to 5, with mode of 4.

TERRITORY/HOME RANGE: Near Westmoreland, Imperial County, Willson (1966) reported 24 territories averaging 1250 ft^2 (116 m^2) in scattered cattail and 75 territories averaging about 350 ft^2 (33 m^2) (actually reported as 300 to 400 ft^2). In Washington, she found territories much larger, ranging from average of 4900 ft^2 (455 m^2) in bulrush to 43,830 ft^2 (4072m^2) in scattered cattail. Breeding birds foraged at least up to 1 mi (1.6 km) from their territories (Willson 1966).

FOOD HABITS: Seeds, insects, and gastropods comprise bulk of diet; newly emergent dragonflies and damselflies the predominant food for nestlings. Food gleaned or hawked from emergent vegetation, wet meadows or grassland, moist earth, or air.

OTHER:

REFERENCES: Bent 1958, Willson and Orians 1963, Willson 1966.



Red-winged Blackbird

B170 (*Agelaius phoeniceus*)

STATUS: No official listed status. Probably permanent resident at lower elevations; summer resident and breeder at higher elevations, usually below 6000 ft (1830 m) but rarely to as high as 8600 ft (2620 m).

DISTRIBUTION/HABITAT: Breeds preferentially in marsh habitat, but also in grasslands, agricultural fields, low shrubs, and small trees. Most common as breeders at lower elevations (annual grasslands up to digger pine-oak type); less common with increasing elevation.

SPECIAL HABITAT REQUIREMENTS: Marshes or shrubs near water for nesting; open terrain.

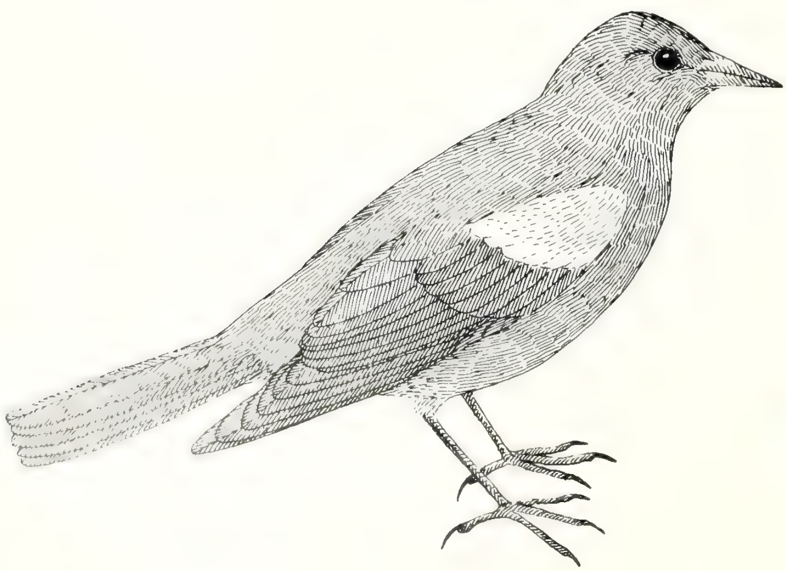
BREEDING: Breeds from mid-March to late July, with peak from early May to late June. Nests usually in marsh vegetation, especially cattails; also in low tufts of grass around ponds, in shrubs, or small trees, most often near water. Nest height varies from 0.5 to 6 ft (0.2 to 1.8 m) above water or ground. Clutch size from 2 to 6, with mean of 3.6.

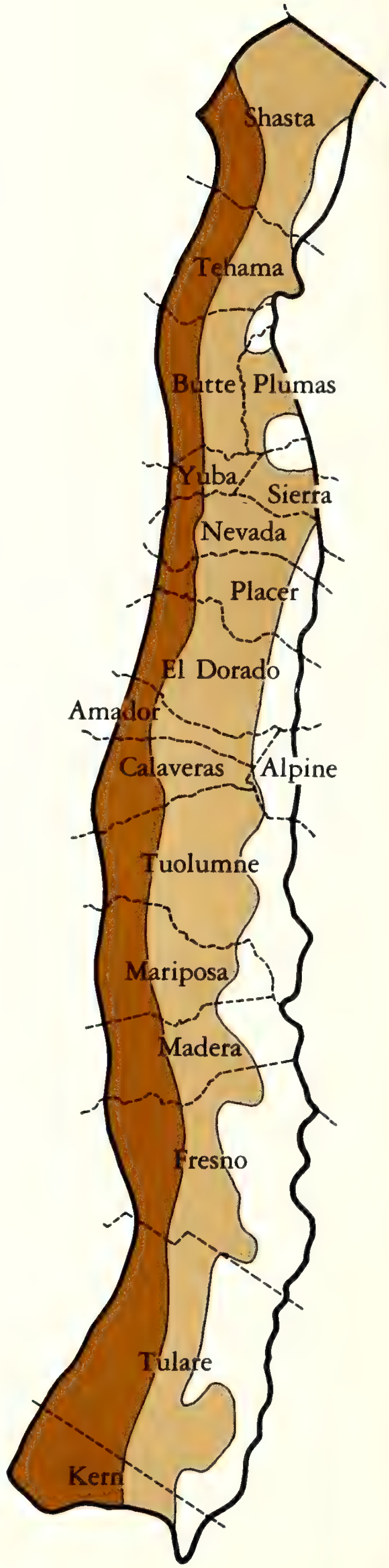
TERRITORY/HOME RANGE: Home range large. For example, in Texas, Meanly (1965) reported nonbreeding birds foraging up to 52 mi (83 km) from roosts. In northern California, 69 breeding territories averaged 0.16 acre (0.06 ha) (Orians 1961).

FOOD HABITS: Seeds, insects, and other arthropods comprise most of diet. Usually feeds in moist places, on ground or in low marsh vegetation, but sometimes in shrubs and trees. Turns over objects in search of food, gleans items from ground or foliage, picks seeds, and hawks aerial insects.

OTHER:

REFERENCES: Orians 1961, Payne 1969, Holm 1973.





Tricolored Blackbird

B171 *(Agelaius tricolor)*

STATUS: No official listed status. Uncommon to rare as breeding species in the western Sierran zone, though breeds regularly in large colonies in the Central Valley. Probably found only as rare vagrant in fall and winter in the western Sierra Nevada.

DISTRIBUTION/HABITAT: Breeds usually in marsh vegetation, sometimes in other very wet situations, such as irrigated fields. Confined to low elevation sites in the western Sierra Nevada. Although fall breeding common in the Central Valley, no such records from west slopes of the Sierra Nevada. Most flocks move toward Sacramento-San Joaquin Delta region in fall and winter.

SPECIAL HABITAT REQUIREMENTS: Typically marshes for nesting; open terrain.

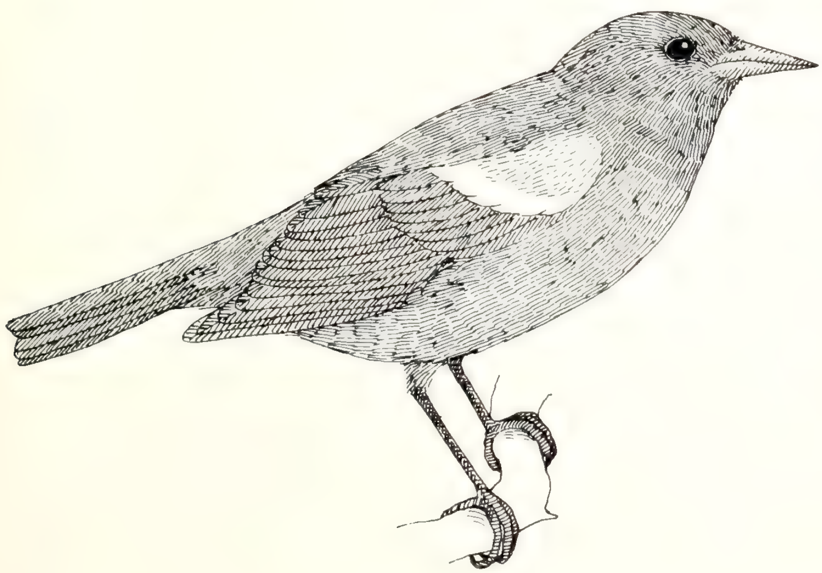
BREEDING: Breeds from early April to mid-July, with peak from early May to late June. May breed from late September to late November, depending upon weather conditions conducive to abundant insect production. Nests usually in dense growths of cattails or other emergent vegetation, sometimes in other low vegetation (willows, blackberries, grain fields, and thistles) in wet areas. Nest height from 1 to 12 ft (0.3 to 3.7 m) over water or ground. Clutch size from 2 to 6, with mean of 3.2.

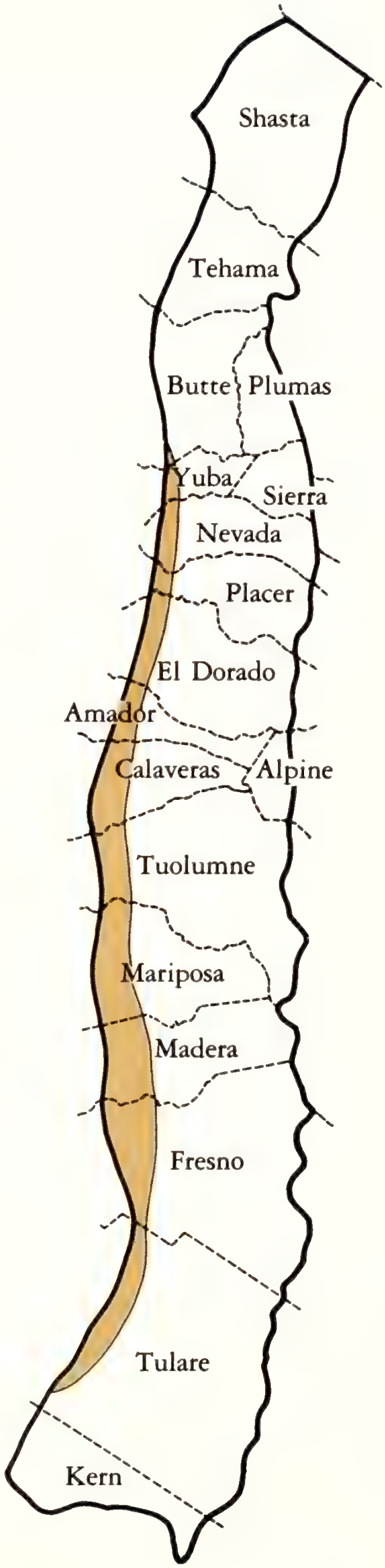
TERRITORY/HOME RANGE: Orians (1961) reported territory confined to about 35 ft^2 (3.3 m^2) around nest. Individual birds studied by Orians in Colusa and Yuba Counties traveled as far as 4 mi (6.4 km) from nest sites to foraging areas; colony as a whole ranged for foraging over about 30 mi^2 (78 km^2).

FOOD HABITS: Insects and seeds comprise diet. Feeds in large flocks, gleaning food from ground and low vegetation in flooded lands, pond margins, or grasslands.

OTHER: Highly gregarious year-round and nests synchronously in large colonies near abundant insect supply.

REFERENCES: Orians 1961, Payne 1969, Dehaven *et al.* 1975.





Northern Oriole

B172 (*Icterus galbula*)

STATUS: No official listed status. Fairly common summer resident and breeder.

DISTRIBUTION/HABITAT: Breeds from blue oak savannahs up to ponderosa pine and black oak types, generally in stands with low percent canopy coverage. Prefers breeding habitat in riparian deciduous sites, generally below 5000 ft (1520 m).

SPECIAL HABITAT REQUIREMENTS:

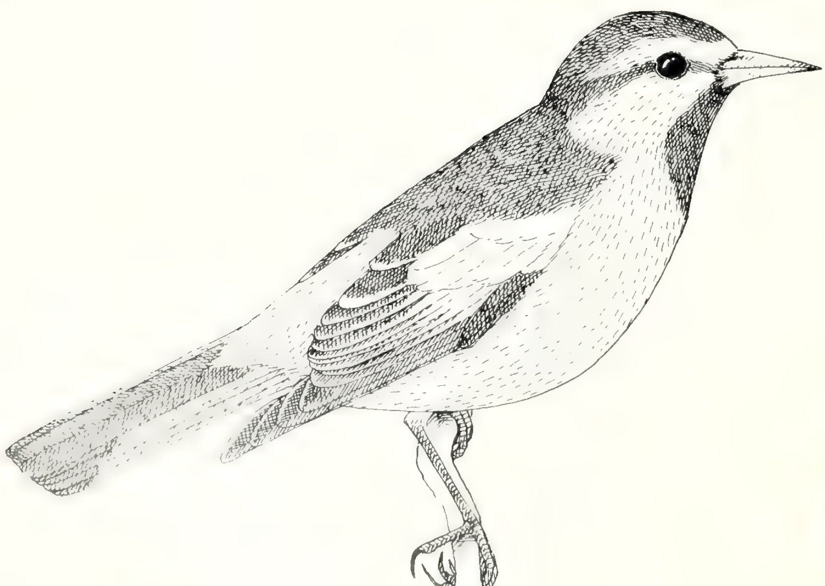
BREEDING: Breeds from early April to late July, with peak from mid-May to early July. Builds hanging nest attached to terminal twigs of riparian deciduous trees and deciduous oaks (occasionally live oaks, orchard trees, or even conifers), from 6 to 50 ft (1.8 to 15 m) up. Clutch size from 3 to 6, with 4 or 5 most common.

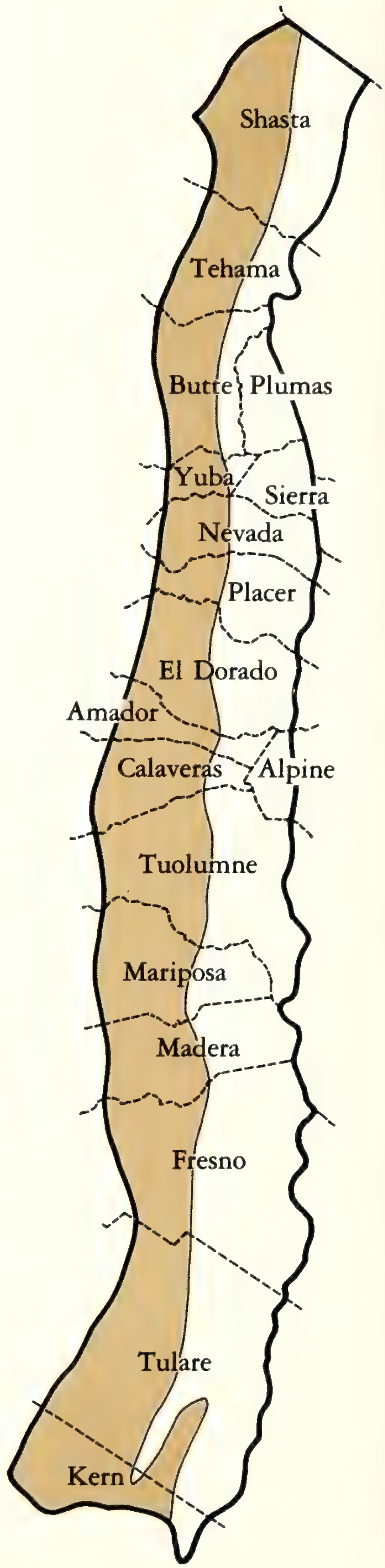
TERRITORY/HOME RANGE: In Kansas, for the Baltimore race of species, Fitch (1958) reported a single territory of 10.5 acres (4.3 ha). In a Montana riparian cottonwood stand, Walcheck (1970) reported a breeding density of 13 pairs per 100 acres (40 ha).

FOOD HABITS: Insects comprise bulk of diet, though some fruit also eaten. Gleans insects from foliage of trees, shrubs, grasses, and forbs; also hawks aerial insects.

OTHER: Water preferred, but nor required, in breeding habitat.

REFERENCES: Grinnell and Storer 1924, Grinnell and Miller 1944, Bent 1958.





Brewer's Blackbird

B173 *(Euphagus cyanocephalus)*

STATUS: No official listed status. Common resident; leaves higher mountains in fall and winter.

DISTRIBUTION/HABITAT: Breeds in all habitat types in the western Sierran zone, except alpine meadow; prefers early successional stages and avoids stands with moderate to high percent canopy cover. Adults and young move upslope in summer, after breeding, but leave higher mountains by late September. Less common at high elevations except around campgrounds, picnic areas, stables, and other areas of human disturbance. In winter, generally remain below ponderosa pine belt.

SPECIAL HABITAT REQUIREMENTS:

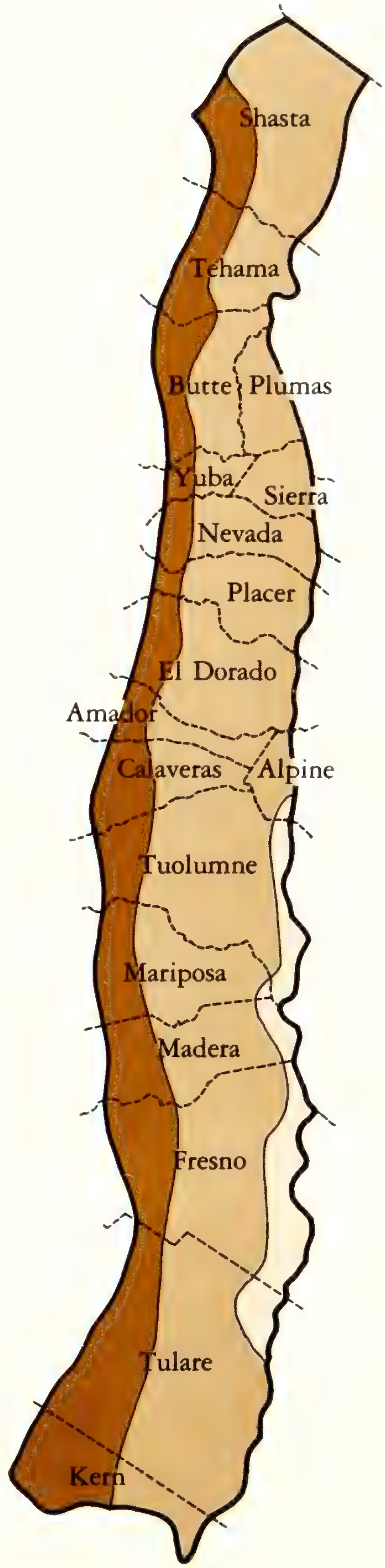
BREEDING: Breeds from mid-March to early August, with peak from early May to early July. Nest sites highly varied. Prefers dense foliage, especially of conifers, but also of other trees, bushes, herbs, and grasses. Also nests in crevices in stumps and occasionally on ground. Nest height ranges from 0 to as high as 150 ft (46 m), though most not above 40 ft (12 m). Clutch size from 3 to 7, with mode of 5.

TERRITORY/HOME RANGE: During breeding season, in eastern Washington, ranged up to 1 mi (1.6 km) from nest (Horn 1968), and Williams (1952) found banded birds up to 6 mi (9.6 km) from nests in Monterey County. Defended territory includes only the nest site (Horn 1968, eastern Washington; Williams 1952, Monterey County).

FOOD HABITS: Food consists mainly of insects, though seeds also eaten, particularly in winter. Usually feeds on ground, digging, turning over objects, and gleaning food uncovered. Gleans from foliage of conifers, shrubs, and emergent vegetation in shallow water. Also hawks aerial insects.

OTHER: Uses drier sites than red-winged blackbirds.

REFERENCES: Williams 1952, Hansen and Carter 1963, Orians and Horn 1969.



Brown-headed Cowbird

B174 *(Molothrus ater)*

STATUS: No official listed status. Common to abundant resident. Irrigation of farmland, mosaic logging, livestock grazing, and urban development contributed to dramatic increase in distribution and abundance of cowbirds into the high Sierra Nevada (Gaines 1977).

DISTRIBUTION/HABITAT: Breeds in all habitat types. Lays its eggs in nests of other species; flexible regarding habitats in which it breeds. Forages most often in open areas, prefers moist sites with short grass. Found most often in and near riparian deciduous woodland or in vicinity of stables, livestock, campgrounds, or picnic areas. In fall and winter, generally found below ponderosa pine belt.

SPECIAL HABITAT REQUIREMENTS: Openings for feeding; trees for roosting.

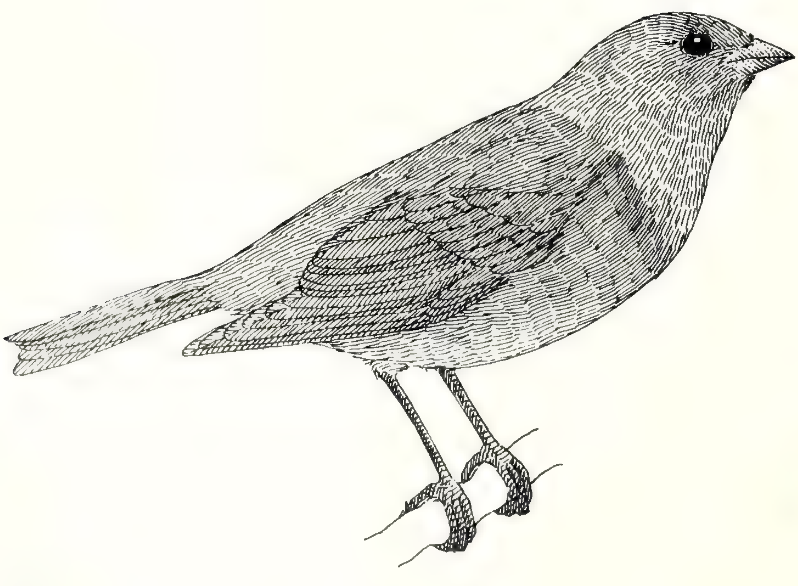
BREEDING: Breeds from early April to late July, with peak in June. Builds no nest, so nest site requirements correspond to those of species it parasitizes (probably all songbirds in range except largest species or cavity nesting forms). Usually one egg laid in each host nest, with each female laying about 30 eggs per season, generally in four groups of 6 to 8 eggs each.

TERRITORY/HOME RANGE: In Michigan, home range size of females ranged from 12 to 40 acres (4.9 to 16 ha), with mean of 24 acres (9.7 ha) (McGeen and McGeen 1968). In Ohio, males had breeding season home ranges generally from 18 to 20 acres (7.3 to 8.1 ha), though some as large as 30 acres (12 ha) (Nice 1937). In Michigan, apparently nonterritorial (Payne 1965), though may defend territories early in morning (S.I. Rothstein, pers. commun.).

FOOD HABITS: Feeds mostly on seeds, also eats insects and spiders. Food usually gleaned from ground and occasionally from backs of livestock.

OTHER: May be responsible for serious population declines of some songbirds in the Sierra Nevada.

REFERENCES: Friedman 1929, Payne 1973, Friedman *et al.* 1977.



Western Tanager

B175 *(Piranga ludoviciana)*

STATUS: No official listed status. Fairly common spring migrant and summer resident.

DISTRIBUTION/HABITAT: Breeds in all coniferous forest types. Prefers stands with mature trees having intermediate percent canopy cover. In spring, migrates through some lower elevation types, down as far as blue oak savannah.

SPECIAL HABITAT REQUIREMENTS:

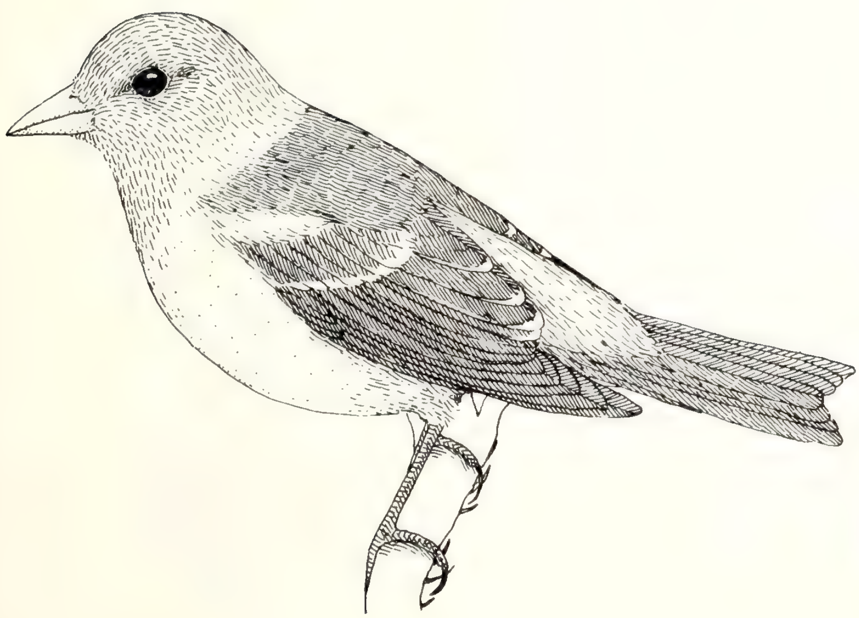
BREEDING: Breeds from early May to mid-August, with peak from early June to late July. Nests toward end of horizontal branch, from 6 to 50 ft (1.8 to 15 m) up. Clutch size from 3 to 5, with mode of 3.

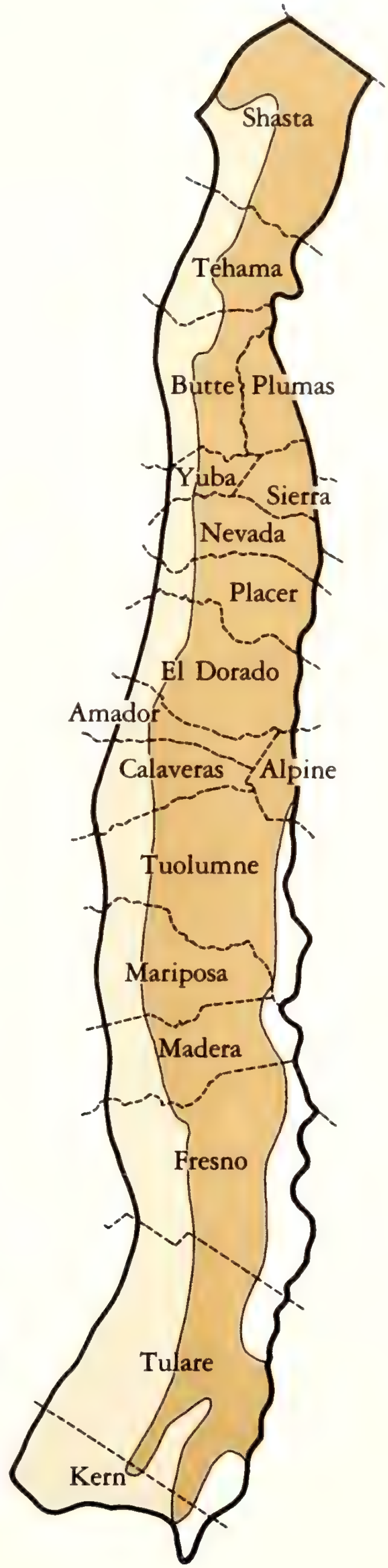
TERRITORY/HOME RANGE: No data available.

FOOD HABITS: Insects and fruits make up bulk of diet. Picks fruit, gleans insects from large twigs, branches, foliage, and ground, and also hawks for aerial insects.

OTHER: Very little research on this species.

REFERENCES: Grinnell and Miller 1944, Bent 1958, Gaines 1977.





Black-headed Grosbeak

B176 *(Pheucticus melanocephalus)*

STATUS: No official listed status. Common summer resident.

DISTRIBUTION/HABITAT: Breeds in wooded sites with some preference for areas with low percent canopy cover, from blue oak savannah up to mixed-conifer zone, usually near water source, occasionally in dry, open woodland. Optimum habitat riparian deciduous. Leaves the western Sierran zone by late summer.

SPECIAL HABITAT REQUIREMENTS:

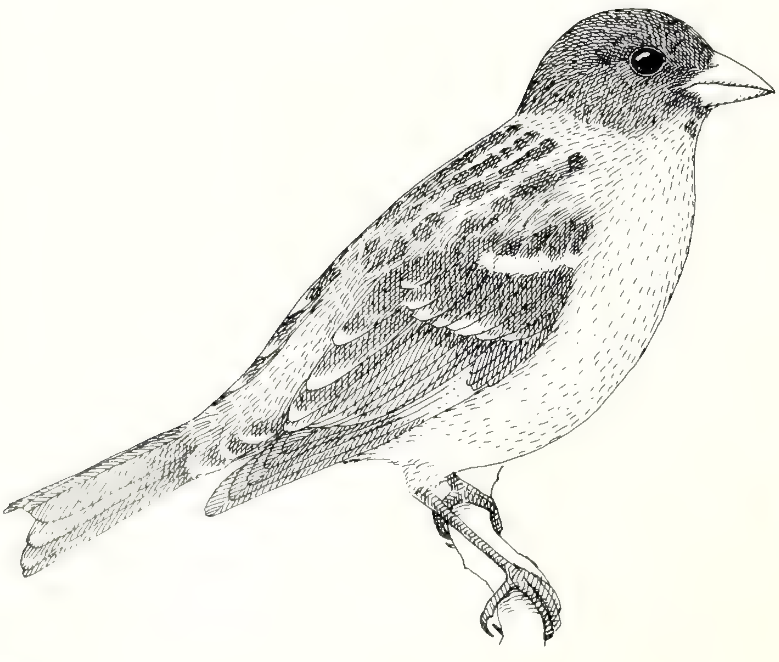
BREEDING: Breeds from late April to early August, with peak from late May to mid-July. Nests usually in deciduous tree or shrub, often near water. Nest height ranges from 3 to 30 ft (0.9 to 9.1 m), though most nests from 6 to 12 ft (1.8 to 3.7 m) up. Clutch size from 2 to 5, with mean of 3.3.

TERRITORY/HOME RANGE: No information available.

FOOD HABITS: Feeds on insects, spiders, fruits, seeds, and buds. Picks fruit and buds from trees and shrubs or from ground; gleans insects from foliage, especially deciduous.

OTHER:

REFERENCES: Grinnell and Miller 1944, Weston 1947, Bent 1968.



Blue Grosbeak

B177 *(Guiraca caerulea)*

STATUS: No official listed status. Rare summer resident.

DISTRIBUTION/HABITAT: Breeds in few sites above 1000 ft (305 m) in the western Sierran foothills, as along Kern River above Lake Isabella; also one record at 1700 ft (520 m) in Mariposa County. Otherwise, no other breeding localities found yet (breeding distribution shown on range map considered potential only; documented sites indicated by stars). Found near water while nesting, foraging in vegetation along water or in open areas nearby. Riparian deciduous type optimum for breeding. Decidely not confined to moist habitats during migration and after breeding.

SPECIAL HABITAT REQUIREMENTS: Dense shrubs near water.

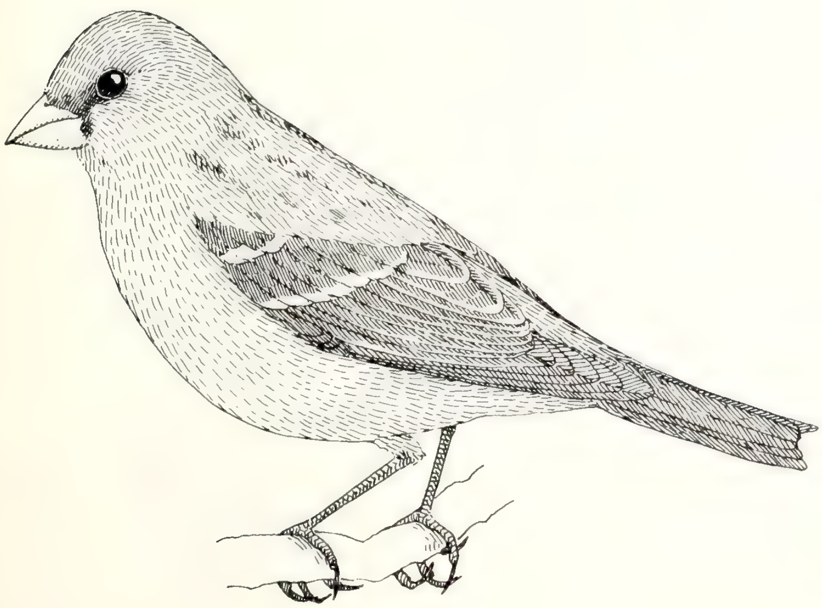
BREEDING: Breeds from late April to late July, with peak from early June to early July. Nests in low, thick vegetation near water, as in willows, cottonwoods, and nettle patches. Nests range from 0.5 to 20 ft (0.15 to 6.1 m) up, most between 2 to 10 ft (0.6 to 3.1 m) above ground. Clutch size from 2 to 5, with mode of 4.

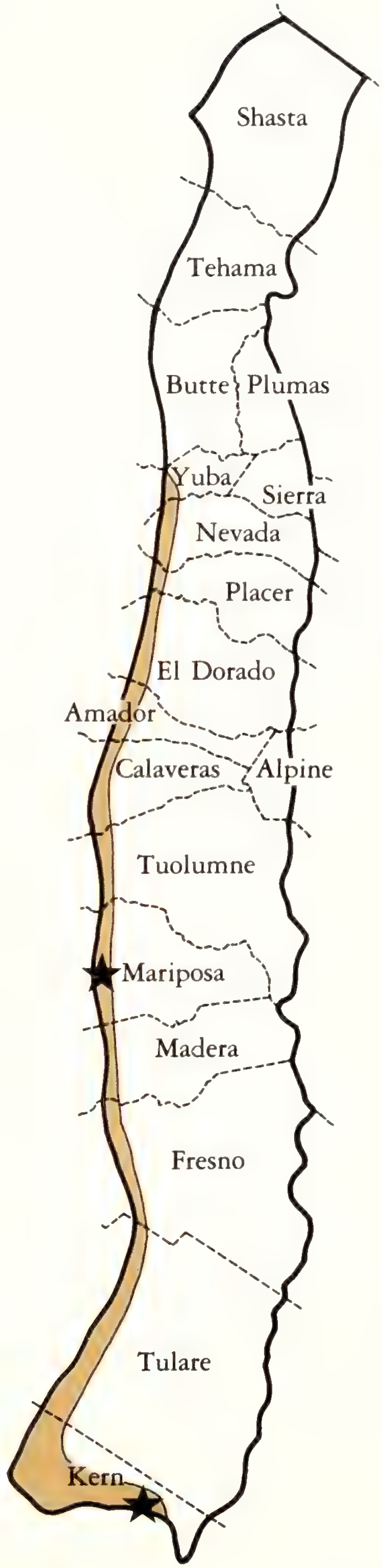
TERRITORY/HOME RANGE: No information on home range size. One breeding territory in South Carolina occupied 15.3 acres (6.2 ha) (Odum and Kuenzler 1955).

FOOD HABITS: Insects and seeds, gleaned mostly from ground, make up diet.

OTHER:

REFERENCES: Grinnell and Storer 1924, Grinnell and Miller 1944, Bent 1968.





Lazuli Bunting

B178 *(Passerina amoena)*

STATUS: No official listed status. Uncommon summer resident and spring migrant.

DISTRIBUTION/HABITAT: Breeds in open areas, shrub lands, and timbered areas with low percent canopy cover, from annual grasslands up to mixed-conifer type. Prefers dense, low vegetation along streams and boggy meadows. Small numbers usually move upslope after breeding, rarely to as high as 10,000 ft (3050 m).

SPECIAL HABITAT REQUIREMENTS: Shrubs/grass-forbs.

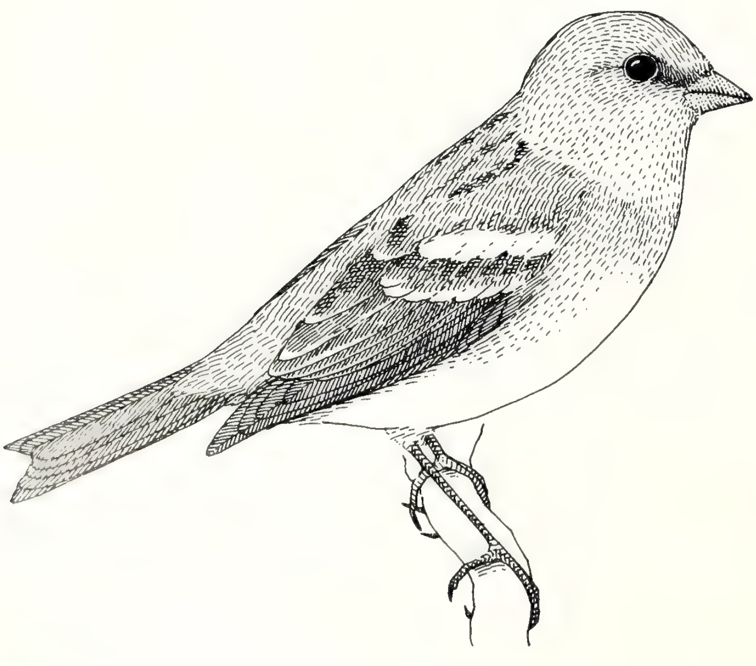
BREEDING: Breeds from late March to mid-August, with peak from early June to late July. Nests in thick growth of brush, forbs, vines, willows, or other low vegetation, usually from 1.5 to 4 ft (0.5 to 1.2 m) up, and usually near water but not over damp ground. Clutch size from 3 to 5, with mode of 4.

TERRITORY/HOME RANGE: Territorial during breeding season; no data available on size of territory or home range.

FOOD HABITS: Feeds on insects and seeds, on the ground, and in low foliage of grasses, forbs, shrubs, trees. Picks seeds and gleans or pounces upon insects.

OTHER:

REFERENCES: Grinnell and Storer 1924, Grinnell and Miller 1944, Bent 1968.



Evening Grosbeak

B179 *(Hesperiphona vespertina)*

STATUS: No official listed status. Uncommon resident; occurrence highly unpredictable at most localities.

DISTRIBUTION/HABITAT: Breeds in mature mixed-conifer and red fir forest. Prefers stands of intermediate percent canopy coverage. Seeks out area with abundant food before nesting, otherwise, highly nomadic. Seems to desert higher elevations in winter; some move downslope in fall and winter to oak and pine/oak habitats of foothills.

SPECIAL HABITAT REQUIREMENTS:

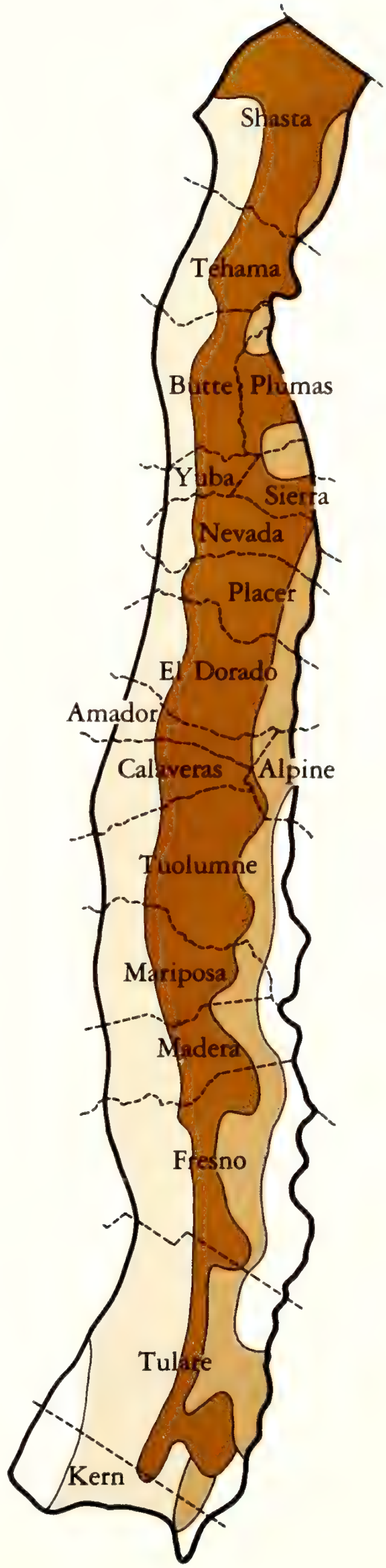
BREEDING: Breeds from early June to early September, with peak from early July to late August. Nests usually above 35 ft (10.7 m) in conifer, though other trees sometimes used. Nest height ranges from 7 to 100 ft (2.1 to 30 m) up. Clutch size from 2 to 5, with mode of 4.

TERRITORY/HOME RANGE: No information available.

FOOD HABITS: Eats mainly large seeds, buds, fruits, and insects. Picks vegetable food from crowns of trees, branch tips, shrubs, and from ground. Insects gleaned from foliage and hawked in air.

OTHER: Usually seen in flocks of 10 to 100.

REFERENCES: Grinnell and Miller 1944, Parks and Parks 1963, Bent 1968.



Purple Finch

B180 *(Carpodacus purpureus)*

STATUS: No official listed status. Fairly common permanent resident in suitable habitat, though numbers fluctuate widely from year to year. Some upslope movement in late summer and downslope movement in fall, winter, and spring periods.

DISTRIBUTION/HABITAT: Breeds in timbered sites from digger pine-oak type up to mixed-conifer forest; prefers higher forest types within that range. Optimum habitat in mature mixed-conifer or ponderosa pine forests with intermediate to high percentage canopy cover. Also breeds in riparian deciduous and black oak habitats. Prefers to breed in moist, shady conifer forests, as in canyon bottoms or near streams or wet meadows. In winter, prefers hardwood to conifers and more open woodland to dense forests.

SPECIAL HABITAT REQUIREMENTS:

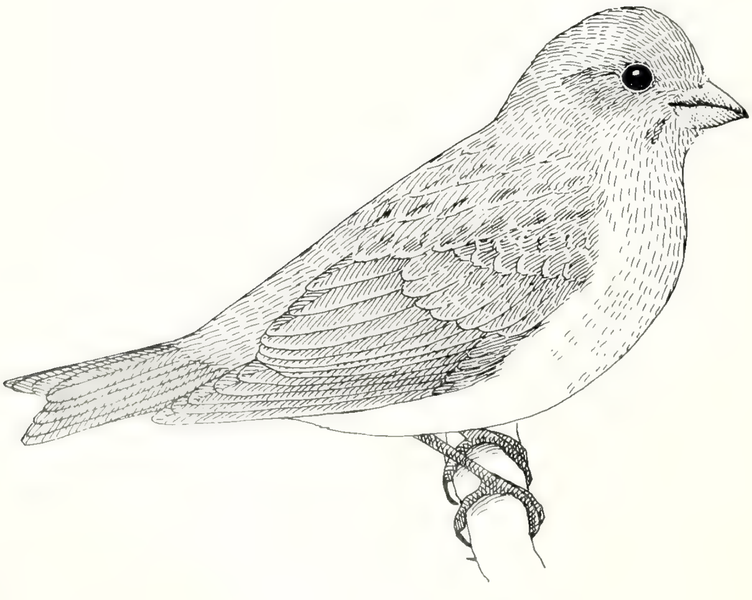
BREEDING: Breeds from early April to mid-August, with peak from mid-May to mid-July. Nests near end of horizontal branch in conifer or deciduous tree, usually near water, and from 6 to 50 ft (1.8 to 15 m) up. Clutch size from 3 to 6, most contain 4 or 5.

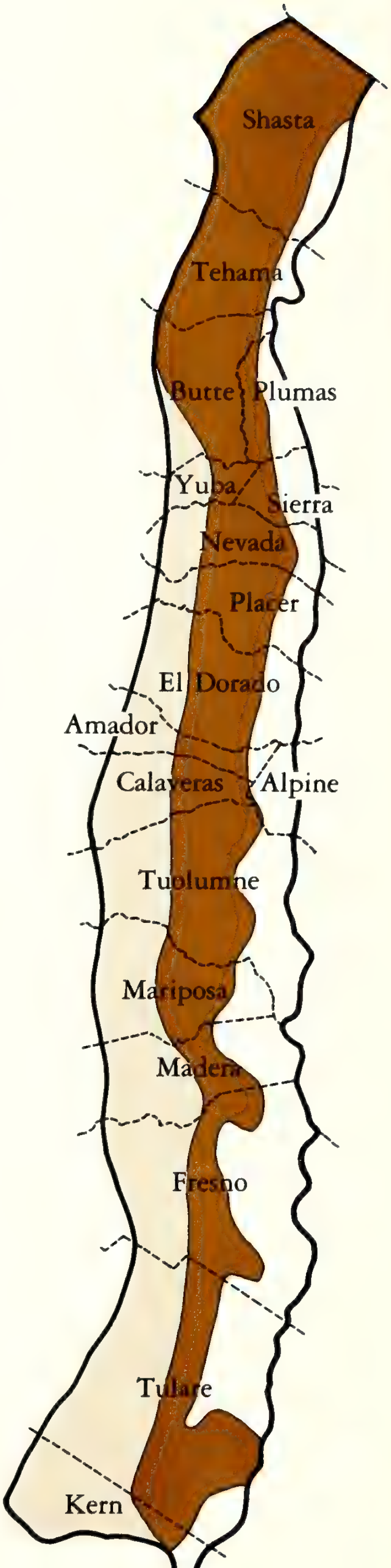
TERRITORY/HOME RANGE: No information.

FOOD HABITS: Eats mainly seeds, buds, flowers, and fruit, and some insects. Removes vegetable food from plants and gleans insects from foliage.

OTHER: Usually found in flocks of 5 to 15, even during breeding season. Favors forest edges for foraging. Easily confused with Cassin's finch, a higher-elevation relative.

REFERENCES: Grinnell and Miller 1944, Salt 1952, Bent 1968.





Cassin's Finch

B181 *(Carpodacus cassinii)*

STATUS: No official listed status. Common resident. Winter distribution poorly known, but apparently much of population moves to east slopes of the Sierra Nevada, remainder moves to lower elevations on west slope.

DISTRIBUTION/HABITAT: Breeds in mature conifer forests from mixed-conifer up to lodgepole pine types; prefers low to intermediate canopy cover. Frequents forest edges more than interior.

SPECIAL HABITAT REQUIREMENTS: Trees/grass-forbs.

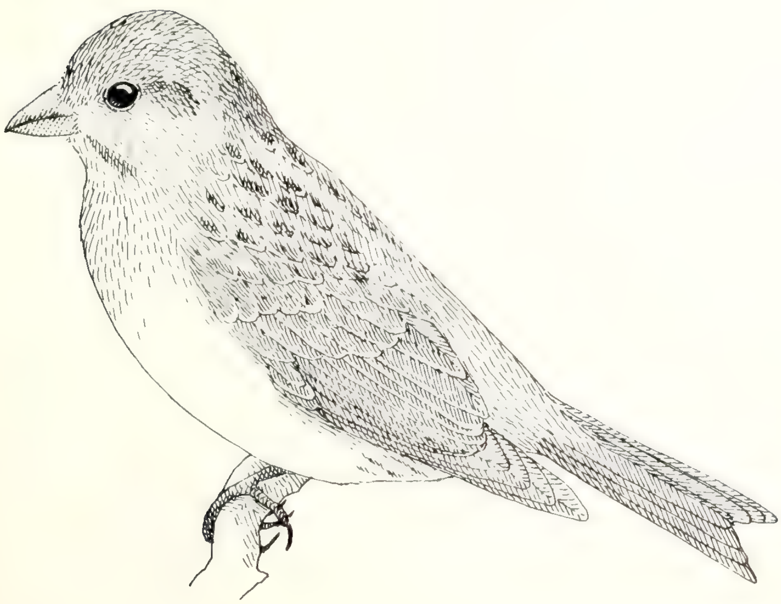
BREEDING: Breeds from mid-May to late August, with peak from late June to early August. Nests near end of flat spray of conifer foliage, exposed to sun from above, from 5 to 150 ft (1.5 to 46 m) up (most nests above 40 ft [12m]). Clutch size from 3 to 6, with 5 most frequent.

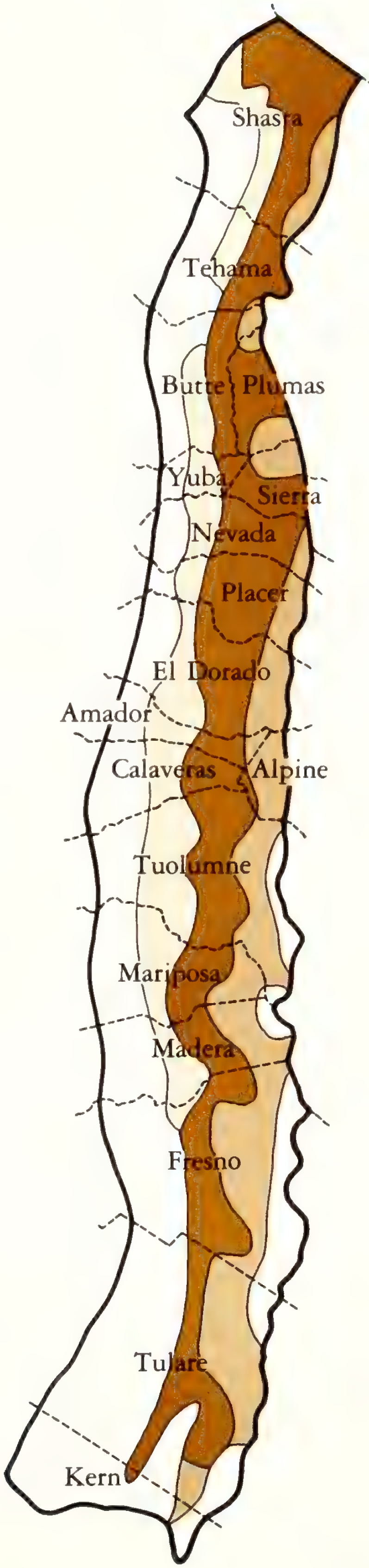
TERRITORY/HOME RANGE: No data on home range. In Utah, males defended no territory but instead followed mate about and defended her from other males (Samson 1976). Tend to breed in loose colonies, with several nests situated close together, even though similar habitat nearby may be vacant.

FOOD HABITS: Feeds on grass and forb seeds, conifer buds and seeds, berries, and insects. Berries, buds, and seeds picked from plants; insects gleaned from foliage; and several food items gleaned from ground.

OTHER: Easily confused with purple finches, which helps to explain uncertainty about winter range. Populations fluctuate widely from year to year.

REFERENCES: Salt 1952, Jones and Baylor 1969, Samson 1976.





House Finch

B182 *(Carpodacus mexicanus)*

STATUS: No official listed status. Abundant resident at lower elevations.

DISTRIBUTION/HABITAT: Breeds commonly in annual grasslands and upslope into chaparral type; prefers early successional stages. No significant seasonal movements.

SPECIAL HABITAT REQUIREMENTS: Elevated perches.

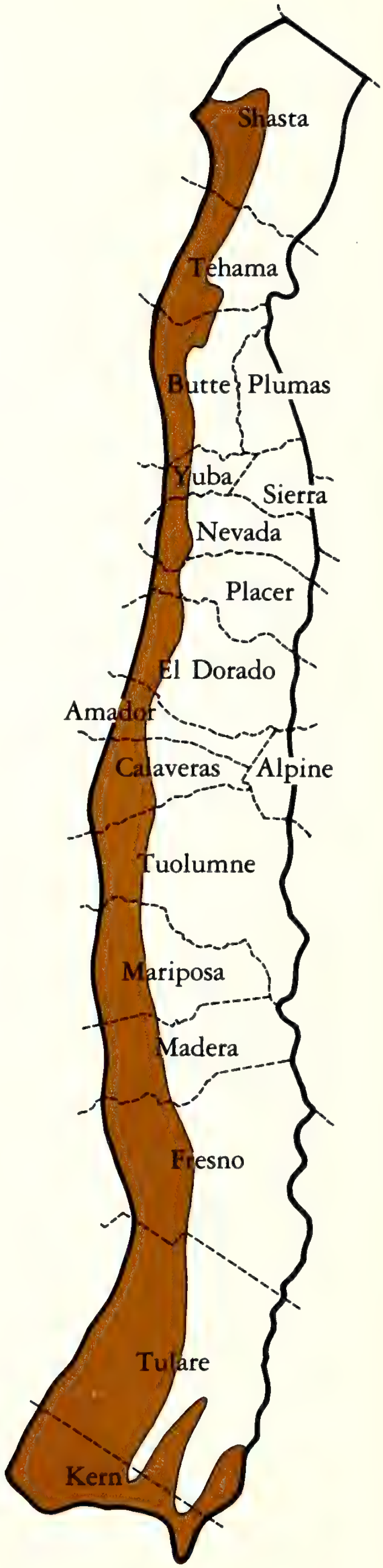
BREEDING: Breeds from mid-March to late August, with peak from mid-April to late June. Nest sites highly varied—a cavity or projection on some man-made structure, dense foliage of trees, old birds' nests, hollow limbs, or crevices in cliff face. Nest generally shaded by foliage or some object, usually from 5 to 20 ft (1.5 to 6.1 m) up, ranging from 3 to 50 ft (0.9 to 15 m). Clutch size from 2 to 6, with mean of 4.5.

TERRITORY/HOME RANGE: No information on home range. In Berkeley, six territories ranged in radius from 6 to 30 ft (1.8 to 9.1 m), averaging 14 ft (4.3 m) around nest (Thompson 1960).

FOOD HABITS: Seeds of grasses and forbs, fruit, and berries comprise most of diet. Gleans from ground, and picks seeds and fruits from grasses and forbs.

OTHER: More numerous around farms, suburbs, and small towns than in natural areas. Prefers open areas with scattered trees, does not *require* trees, but needs overhead perch of some sort (powerlines, buildings, or other) for escape.

REFERENCES: Salt 1952, Evenden 1957, Thompson 1960.



Pine Grosbeak

B183 *(Pinicola enucleator)*

STATUS: No official listed status. Uncommon resident; population numbers fluctuate markedly from year-to-year.

DISTRIBUTION/HABITAT: Breeds in red fir, lodgepole pine, and high elevation riparian deciduous sites. Prefers stands with large trees and low to intermediate percent canopy cover. Usually found near edges of meadows or streams. No evidence of regular downslope movement for winter months, but few records in habitats below breeding range for nonbreeding period.

SPECIAL HABITAT REQUIREMENTS: Nearby meadows or streams.

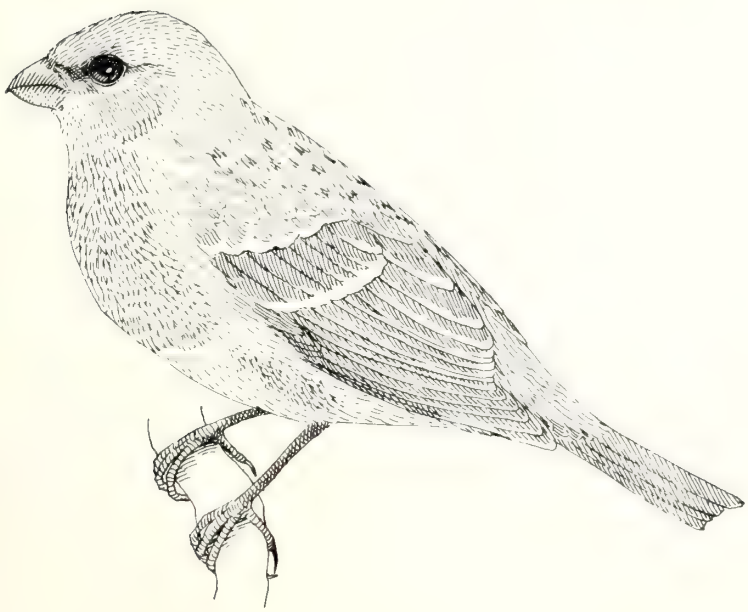
BREEDING: Breeds from late May to early August, with peak from mid-June to late July. Nests in thick foliage near end of horizontal bough or conifer, from 16 to 35 ft (4.9 to 10.7 m) up. Clutch size from 2 to 5, most contain 4.

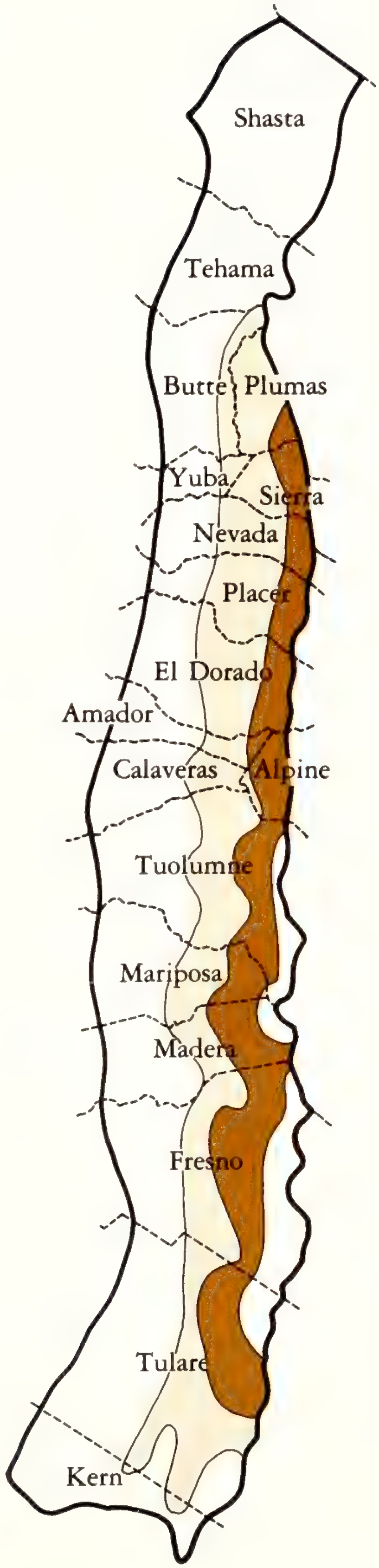
TERRITORY/HOME RANGE: No information on home range. In a Utah spruce-fir forest, a single breeding territory covered 26 acres (10.5 ha) (French 1954).

FOOD HABITS: Eats mainly buds and seeds of conifers and deciduous trees; also fruit, other seeds, and insects. Picks and gleans food from trees, shrubs, and ground. Moves slowly and deliberately when foraging.

OTHER:

REFERENCES: Grinnell and Miller 1944, French 1954, Bent 1968.





Gray-crowned Rosy Finch

B184 (*Leucosticte tephrocotis*)

STATUS: No official listed status. Common permanent resident in suitable habitat.

DISTRIBUTION/HABITAT: Breeds in alpine meadows, where remains year-round. Sometimes, especially in spring, wanders downslope to elevation as low as 8000 ft (2440 m) in earliest successional stage of lodgepole pine forests. May also be noted rarely in whitebark pine, hemlock, and lodgepole forests adjacent to alpine meadows.

SPECIAL HABITAT REQUIREMENTS: Crevices, talus, or rock outcrops for nest cover.

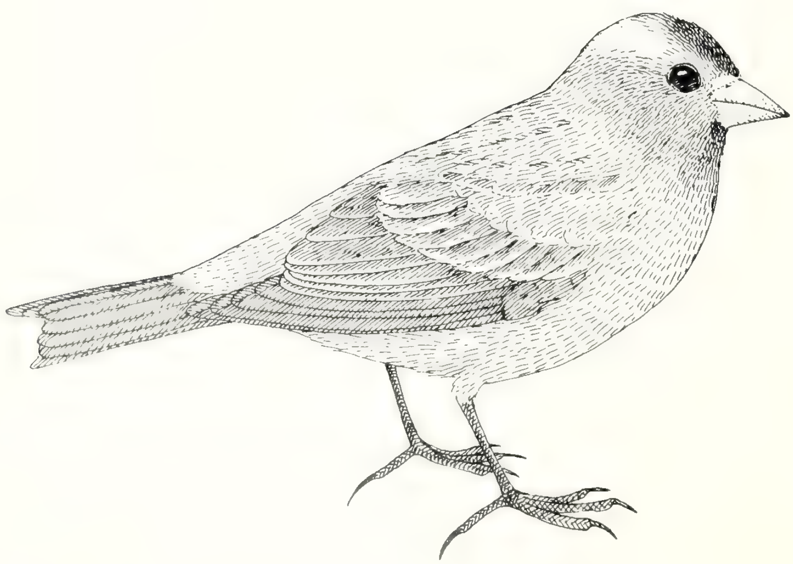
BREEDING: Breeds from early June to mid-August, with peak from late June to early August. Nests in crevices in cliffs, rockslides, and moraines; usually set back in niches or under boulders. Clutch size from 3 to 5, with mean of 4.

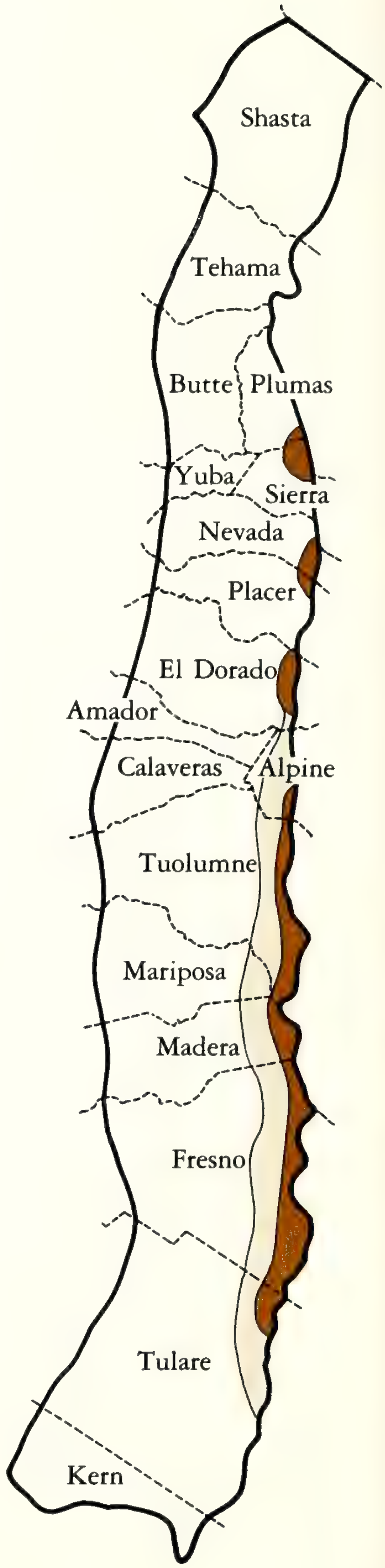
TERRITORY/HOME RANGE: Males do not actively defend territory, but only immediate vicinity of mate to keep other males away (Twining 1938). Twining also reported breeders foraged at least 0.5 mi (0.8 km) from nests.

FOOD HABITS: Feeds on insects and seeds, proportions varying with what is most readily available. Obtains food from patches of bare ground, edges of snowbanks, from shallow water, foliage, and air. Picks food from ground, rarely from foliage; hawks insects.

OTHER:

REFERENCES: Twinning 1940; Johnson 1965, 1975.





Pine Siskin

B185 *(Carduelis pinus)*

STATUS: No official listed status. Widespread and fairly common permanent resident; numbers fluctuate because of nomadic behavior in response to food supply and climatic conditions.

DISTRIBUTION/HABITAT: Breeds in coniferous forests from ponderosa pine belt up to lodgepole pine forests, where most abundant (Beedy, unpubl.). Prefers stands with low to intermediate percent canopy coverage. At times, noted below nesting range.

SPECIAL HABITAT REQUIREMENTS:

BREEDING: Breeds from early April to early July, with peak from late April to late June. Nests well concealed amid dense foliage of horizontal limbs of tall conifers, though oaks and maples used occasionally. Nest height ranges from 6 to 50 ft (1.8 to 15 m). Clutch size from 1 to 5, with mean of 3.

TERRITORY/HOME RANGE: No information available on home range. In New Hampshire, Weaver and West (1943) reported territory sizes as ranging from 3 to 6 ft (0.9 to 1.8 m) diameter areas, centered on nest.

FOOD HABITS: Opportunistic feeder, eating buds and sap of conifers, seeds, and insects. Strongly attracted to salt licks. Takes food from foliage, bark of conifers, and from ground, by gleaning and picking. Usually feeds in flocks.

OTHER:

REFERENCES: Grinnell and Miller 1944, Sumner and Dixon 1953, Bent 1968.

American Goldfinch

B186 *(Carduelis tristis)*

STATUS: No official listed status. Common resident in suitable habitat.

DISTRIBUTION/HABITAT: Breeds in blue oak savannahs, digger pine-oak woodlands, and particularly in low elevation riparian groves. In late summer and fall, some upslope movement, especially in chaparral type and along riparian corridors.

SPECIAL HABITAT REQUIREMENTS: Streams adjacent to open terrain.

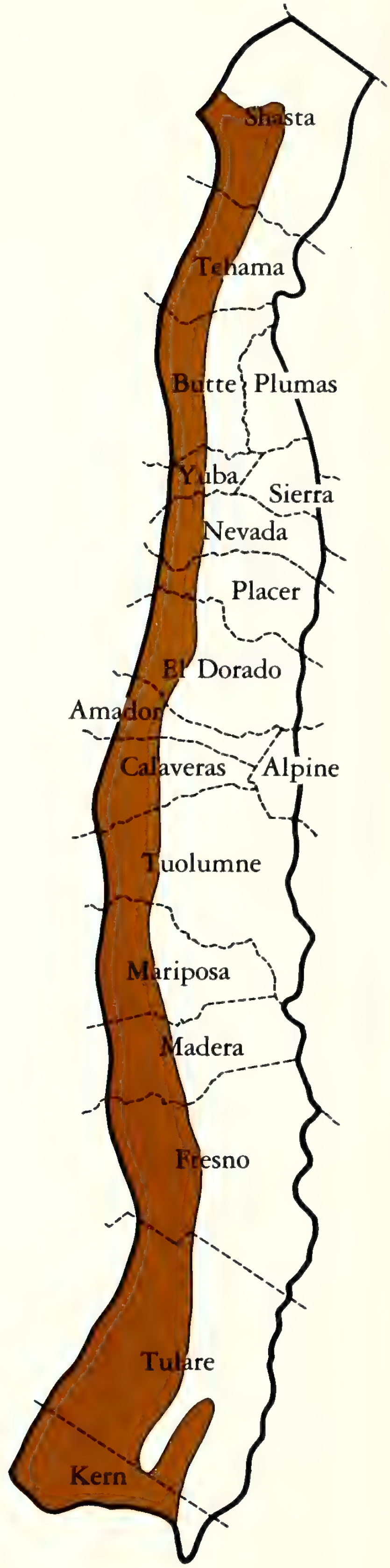
BREEDING: Breeds from early April to late July, with peak from mid-May to mid-July. Nests usually in crotch of shrub or tree, varying in height from 3 to 15 ft (0.9 to 4.6 m). Clutch size from 2 to 7, with mean of 5.

TERRITORY/HOME RANGE: In Michigan, Coutlee (1967) reported territories up to 98 ft (30 m) in diameter, with birds traveling to feeding sites as much as 0.5 mi (0.8 km) away. Stokes (1950) reported Michigan birds in his study had territories from 30 to 90 ft (9.1 to 27 m) in diameter around nest. Nickell (1951) found nesting goldfinches feeding up to 900 ft (274 m) from nest.

FOOD HABITS: Eats mainly seeds of trees and forbs, especially of composites; also some insects. Generally feeds in flocks, picking and gleaning food from flower heads and foliage of forbs, shrubs, and trees.

OTHER:

REFERENCES: Stokes 1950, Nickell 1951, Bent 1968.



Lesser Goldfinch

B187 *(Carduelis psaltria)*

STATUS: No official listed status. Common resident and breeder in suitable habitat.

DISTRIBUTION/HABITAT: Breeds in timbered stages of lower elevation habitats from blue oak savannah up to ponderosa pine and black oak woodlands. Prefers sites with low to intermediate percent canopy coverage. In late summer and fall, some wander upslope to as high as lodgepole pine forests, particularly in sites with shrubs and few or no trees.

SPECIAL HABITAT REQUIREMENTS: Trees/shrubs; dense shrubs; water for breeding.

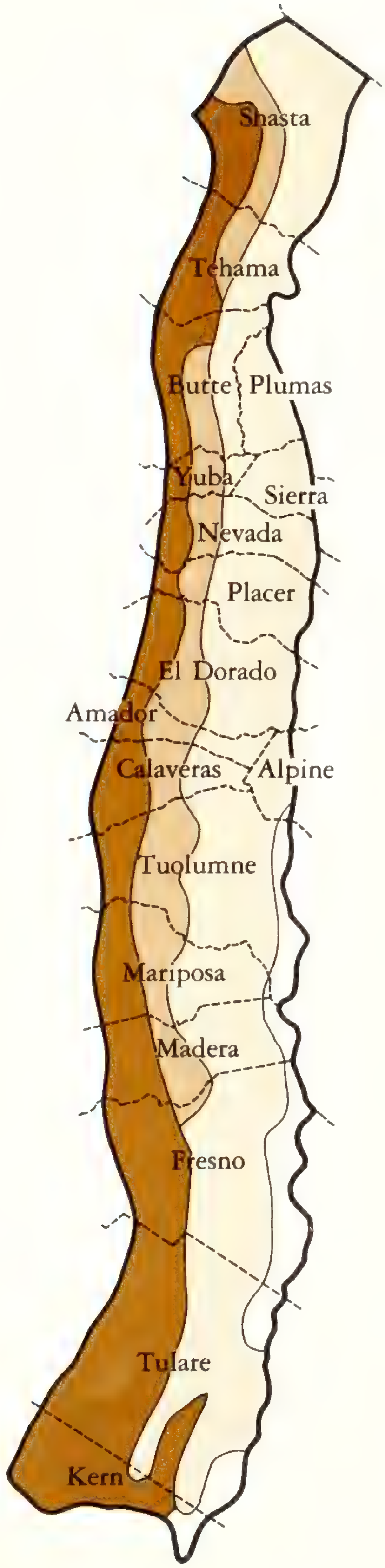
BREEDING: Breeds from late April to late July, with peak from mid-May to mid-July. Nests in terminal foliage, often on drooping branches of shrub or tree; shade required. Nest height ranges from 2 to 30 ft (0.6 to 9.1 m). Clutch size from 3 to 5, with mean of 4.

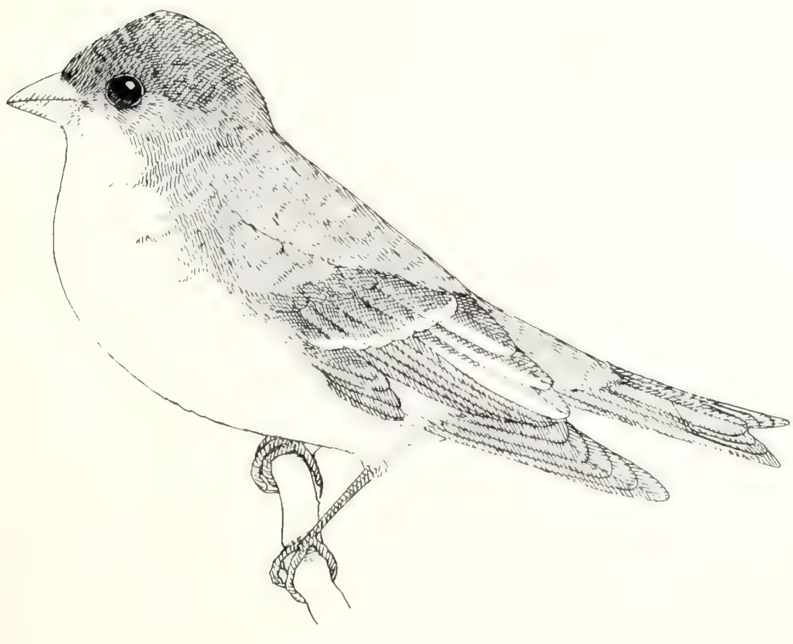
TERRITORY/HOME RANGE: Coutlee (1968a) found area with a diameter of about 98 ft (30 m) around nest defended, and birds traveled up to 0.5 mi (0.8 km) to forage.

FOOD HABITS: Eats weed seeds, buds, fruits, and small quantities of insects. Strongly attracted to salt licks. Gleans food near ground, as in low-growing composites, and rarely in tree crowns. Feeds in flocks.

OTHER:

REFERENCES: Linsdale 1957; Bent 1968; Coutlee 1968a, 1968b.





Lawrence's Goldfinch

B188 *(Carduelis lawrencei)*

STATUS: No official listed status. Rare spring and summer resident, with only a few winter records.

DISTRIBUTION/HABITAT: Breeds at lower elevations, in blue oak savannahs, digger pine-oak woodlands, and riparian deciduous areas. Prefers timbered sites with intermediate percent canopy coverage. Erratic in distribution and abundance throughout range.

SPECIAL HABITAT REQUIREMENTS: Oaks; water for breeding.

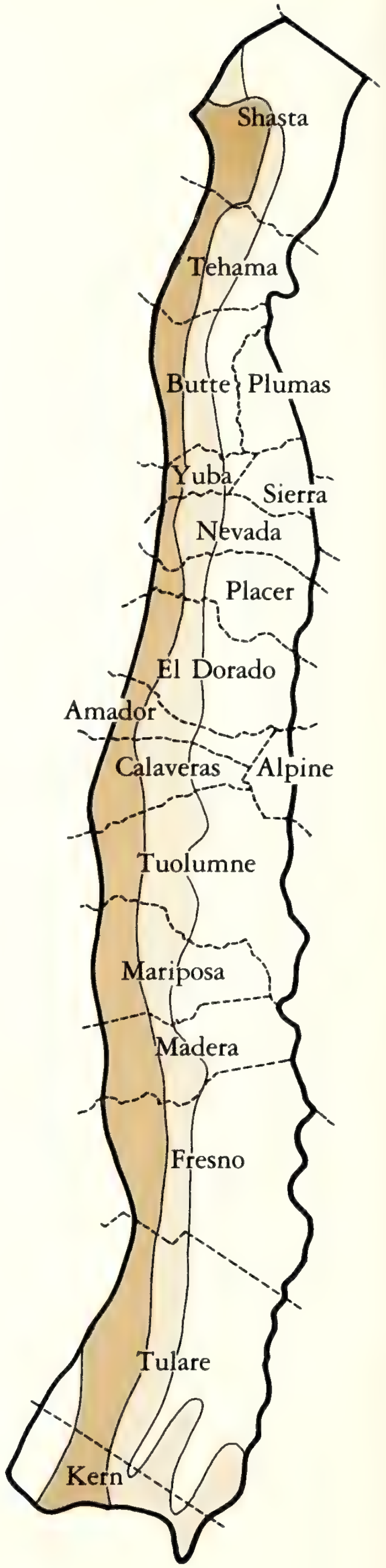
BREEDING: Breeds from early April to mid-July, with peak from early May to late June. Nests generally on hillsides covered by dense stands of oak, with water nearby. Nests in colonies. Nest height varies from 20 to 30 ft (6.1 to 9.1 m). Clutch size from 3 to 6, with mean of 4.

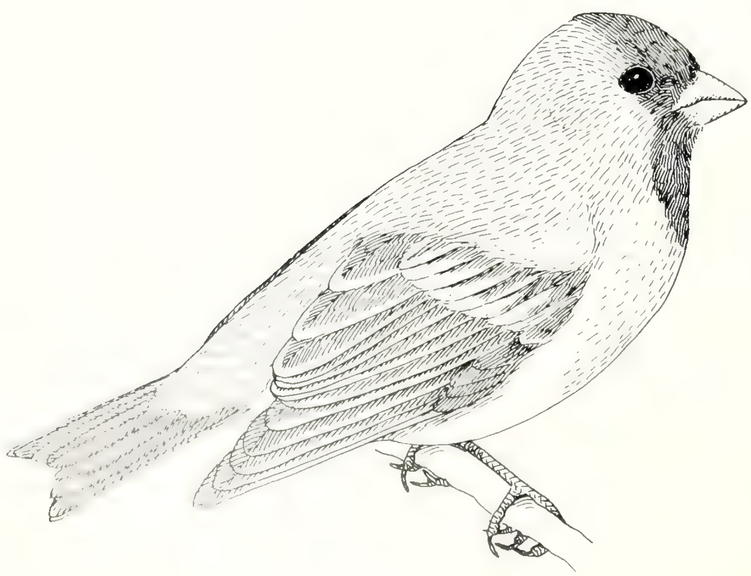
TERRITORY/HOME RANGE: No data on home range. In southern California, Linsdale (1950) reports a territory with radius around nest of 30 to 36 ft (9.1 to 11 m). Coutlee (1968a) states territory ranges from about 33 to 49 ft (10 to 15 m) in diameter.

FOOD HABITS: Weed seeds comprise the diet. In winter, concentrates on chamise achenes; in early summer, nearly restricted to patches of fiddleneck (Boraginaceae). Feeds in flocks, gleaning foliage and ground.

OTHER:

REFERENCES: Grinnell and Miller 1944; Linsdale 1950; Coutlee 1968a, 1968b.





Red Crossbill

B189 *(Loxia curvirostra)*

STATUS: No official listed status. Fairly common but erratic resident of higher mountains; nomadic throughout range.

DISTRIBUTION/HABITAT: Breeds in red fir and lodgepole pine forests; prefers stands with low percent canopy cover. Extremely gregarious, highly nomadic in response to changes in conifer seed production, even descending into valley and foothills in some years (Grinnell and Storer 1924).

SPECIAL HABITAT REQUIREMENTS: Abundant cone crop for breeding.

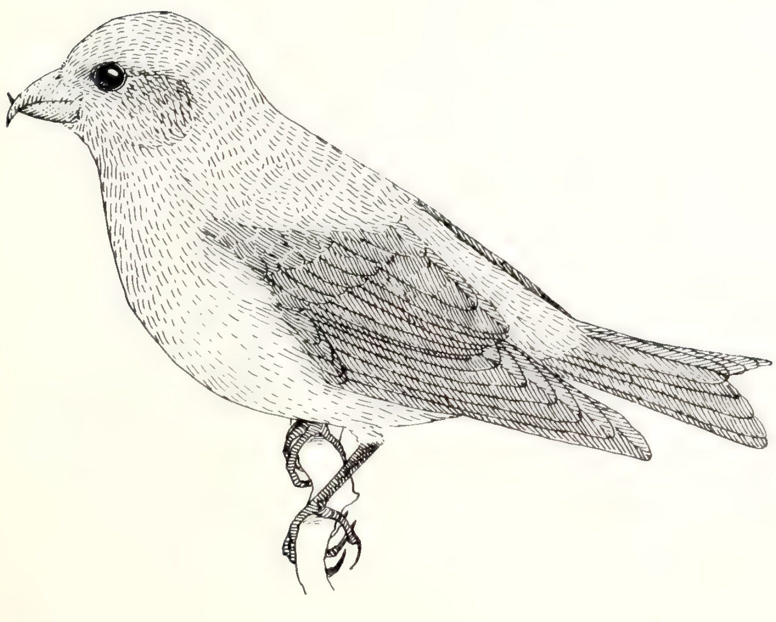
BREEDING: Throughout range, noted breeding in all months of year (Bent 1968), requiring only suitable conifer seed supply. Breeds mostly from February through June. Nests typcially out on horizontal branch of conifer, ranging in height from 12 to 40 ft (3.7 to 12 m). Clutch size from 3 to 5, with mode of 3.

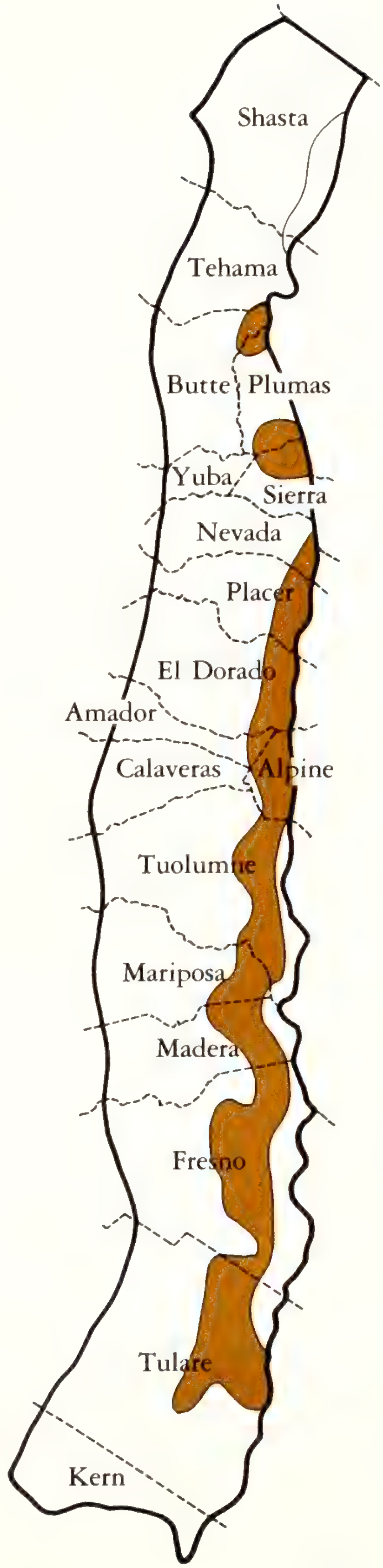
TERRITORY/HOME RANGE: No data available on home range size; territoriality not noted (Snyder 1954).

FOOD HABITS: Eats mainly conifer seeds, primarily lodgepole pine and hemlock, and some insects. Feeds on ground at tips of cone-bearing branches in tree tops, prying seeds from cones with highly modified, crossed mandibles. Both bill and tongue used in extracting seeds.

OTHER:

REFERENCES: Grinnell and Storer 1924, Sumner and Dixon 1953, Bent 1968.





Green-tailed Towhee

B190 (*Pipilo chlorurus*)

STATUS: No official listed status. Uncommon spring and summer resident.

DISTRIBUTION/HABITAT: Breeds in sites with dense shrubs from chaparral zone up to lodgepole pine forests. Generally absent from areas with intermediate to high percent canopy coverage. Particularly associated with dry, brushy slopes of manzanita and ceanothus, a habitat shared with fox sparrow.

SPECIAL HABITAT REQUIREMENTS: Dense shrubs.

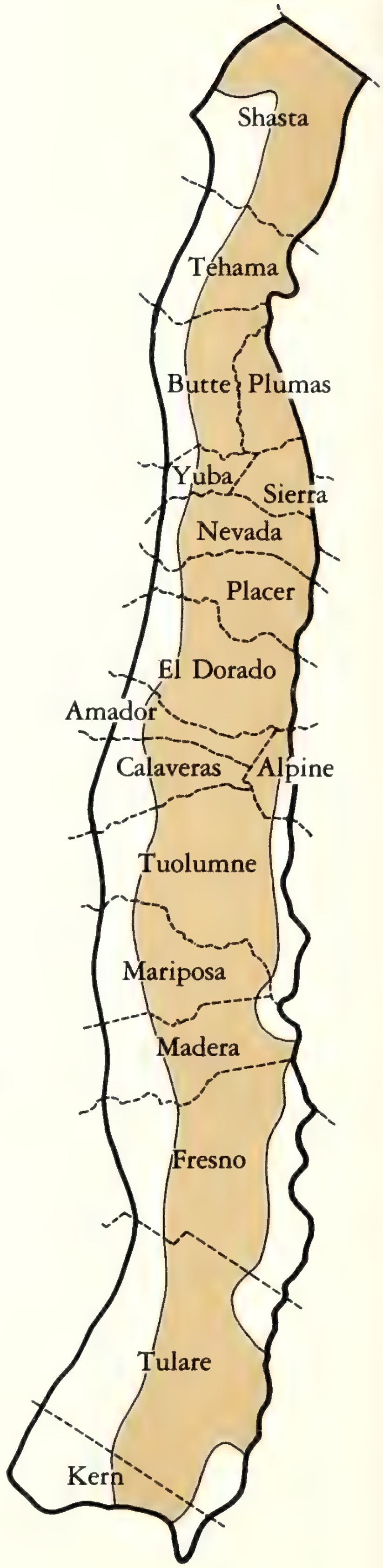
BREEDING: Breeds from mid-April to late July, with peak from late May to early July. Nests well concealed in dense brush, on or near ground. Clutch size from 2 to 5, with 3 or 4 most frequent.

TERRITORY/HOME RANGE: In Colorado, Hering (1948) reported two territories as 0.2 and 0.4 acre (0.08 and 0.16 ha). No information available on home range.

FOOD HABITS: Eats primarily seeds of weeds and shrubs, and some wild berries and insects. Scratches in leaf litter on ground, and gleans food uncovered.

OTHER:

REFERENCES: Grinnell and Storer 1924, Grinnell and Miller 1944, Bent 1968.



Rufous-sided Towhee

B191 *(Pipilo erythrophthalmus)*

STATUS: No official listed status. Common resident at low to middle elevations; rare upslope movement in fall.

DISTRIBUTION/HABITAT: Breeds from blue oak savannahs up to mixed-conifer forests; prefers sites with low percent canopy cover and *dead* brush to provide high concentration of decaying organic material for feeding.

SPECIAL HABITAT REQUIREMENTS: Dense shrubs; litter.

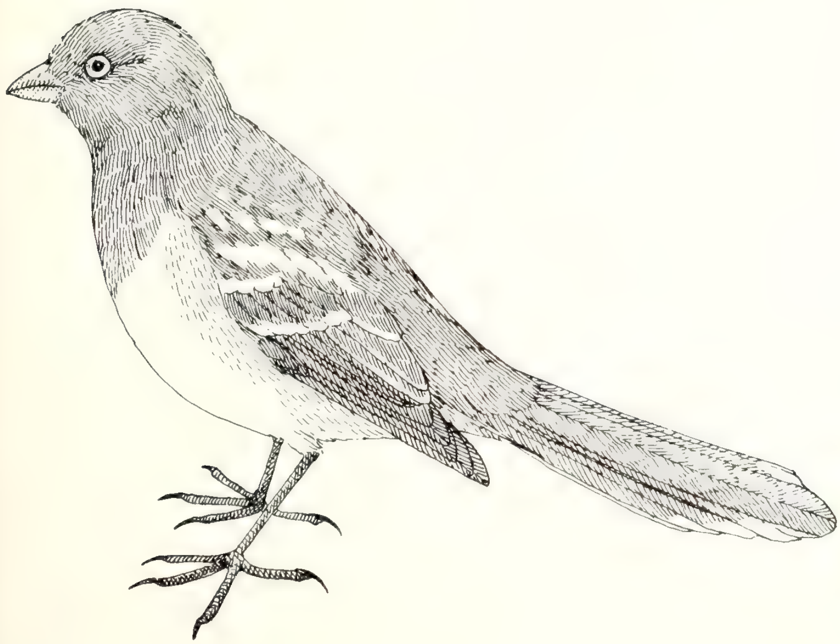
BREEDING: Breeds from late April to mid-July, with peak from mid-May to late June. Nests on ground or in low shrub, usually in well-concealed thicket edge with isolated trees and shrubs, often near piles of dead brush. Clutch size from 2 to 6, most contain 4 or 5.

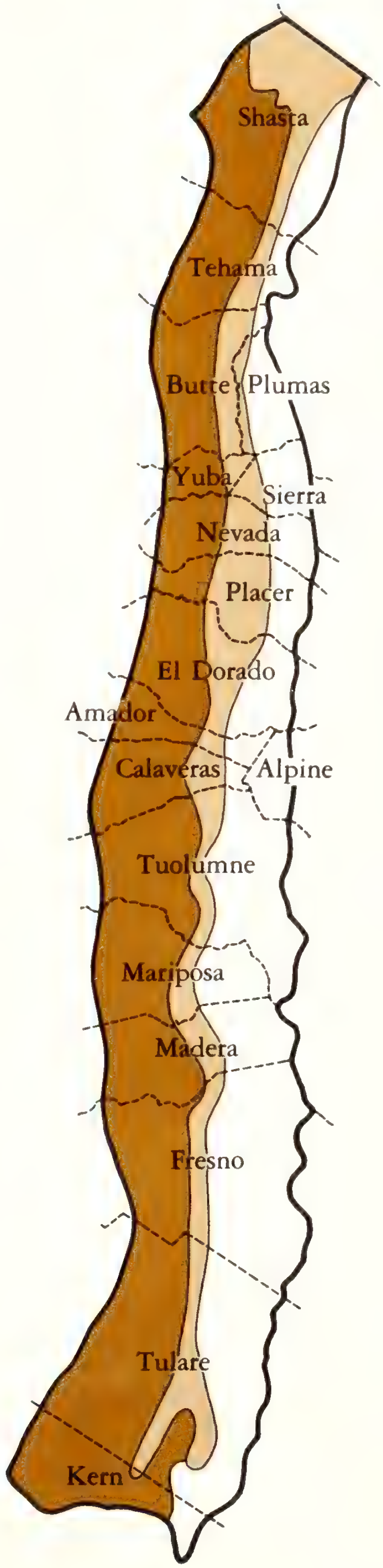
TERRITORY/HOME RANGE: Territories in coastal California chaparral site ranged from 2 to 2.8 acres (0.8 to 1.1 ha) (Mans 1961). In Kansas, Fitch (1958) found territories to range from 1.9 to 6.7 acres (0.8 to 2.7 ha) with mean of 4.4 acres (1.8 ha) (n = 7). Little information on home range size. In Kentucky, Barbour (1941) found winter home ranges of two flocks to cover 9.3 and 31 acres (3.8 and 12.6 ha).

FOOD HABITS: Eats insects (many caterpillars when nesting), spiders, and seeds. Takes most food from ground by scratching and digging in leaf litter. Sometimes gleans foliage.

OTHER: Slash piles in logged areas of conifer forests may provide suitable foraging sites, especially in fall.

REFERENCES: Baumann 1959, Davis 1960, Bent 1968.





Brown Towhee

B192 (*Pipilo fuscus*)

STATUS: No official listed status. Common resident at low elevations.

DISTRIBUTION/HABITAT: Breeds in blue oak savannahs, digger pine-oak woodlands, chaparral, and low elevation riparian deciduous habitats; prefers sites with few or no trees.

SPECIAL HABITAT REQUIREMENTS: Dense shrubs; shrubs/grass-forbs.

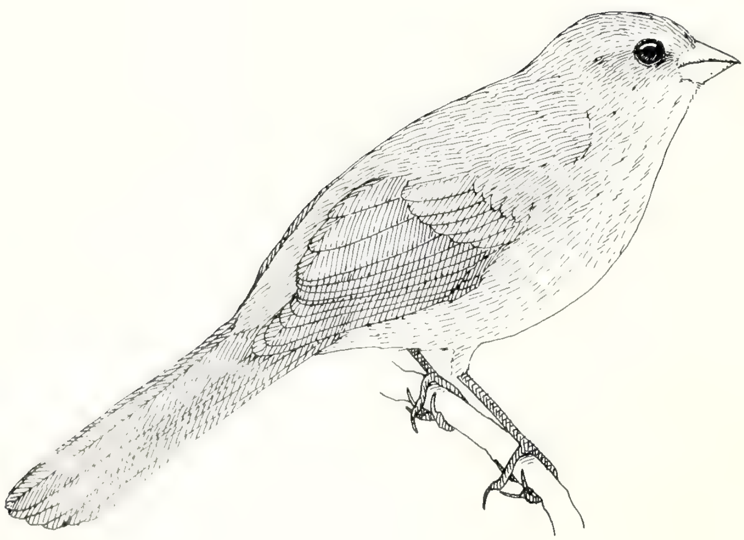
BREEDING: Breeds from early April to late June, with peak from early May to mid-June. Nests in low, dense brush where well concealed; also nests in trees occasionally, at heights up to 20 ft (6.1 m). Clutch size usually 3 or 4.

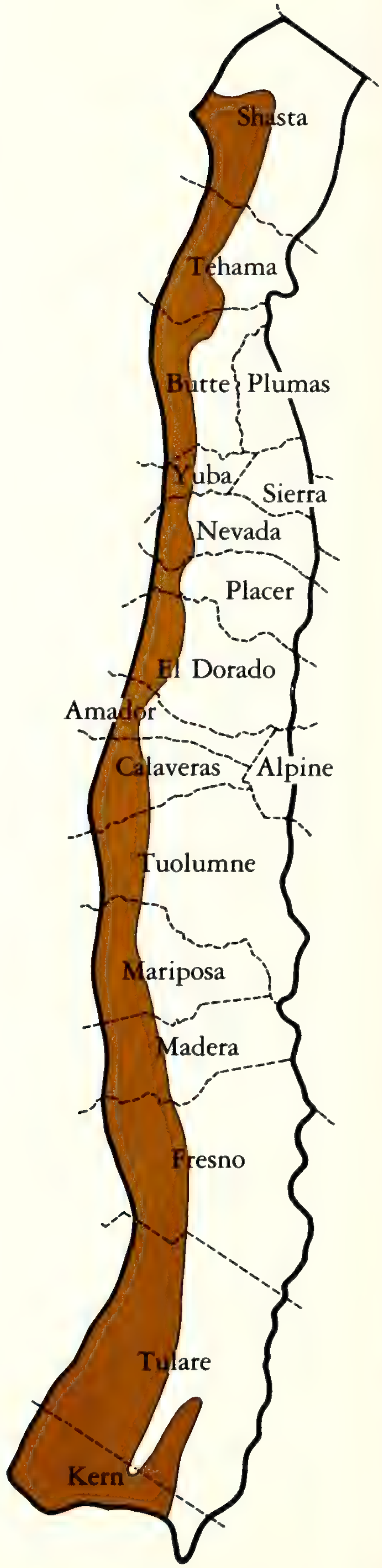
TERRITORY/HOME RANGE: No information on home range. In a California residential area, Bent (1968) reported that territories usually averaged from 1 to 2 acres (0.4 to 0.8 ha), though they ranged up to 5 acres (2 ha).

FOOD HABITS: Feeds on insects, weed seeds, and some fruit. Obtains food primarily from ground, scratches in leaf litter and gleans food uncovered.

OTHER: Activities such as grazing, farming, logging, road building, and landscaping resulted in new habitats, allowing for localized expansion of range.

REFERENCES: Grinnell and Miller 1944, Davis 1951, Bent 1968.





Savannah Sparrow

B193 *(Passerculus sandwichensis)*

STATUS: No official listed status. Common fall and winter visitor to low elevations; occasional summer and fall visitor to middle and high elevations.

DISTRIBUTION/HABITAT: Essentially confined to grassland habitats; may be found in early successional stages of other habitat types.

SPECIAL HABITAT REQUIREMENTS:

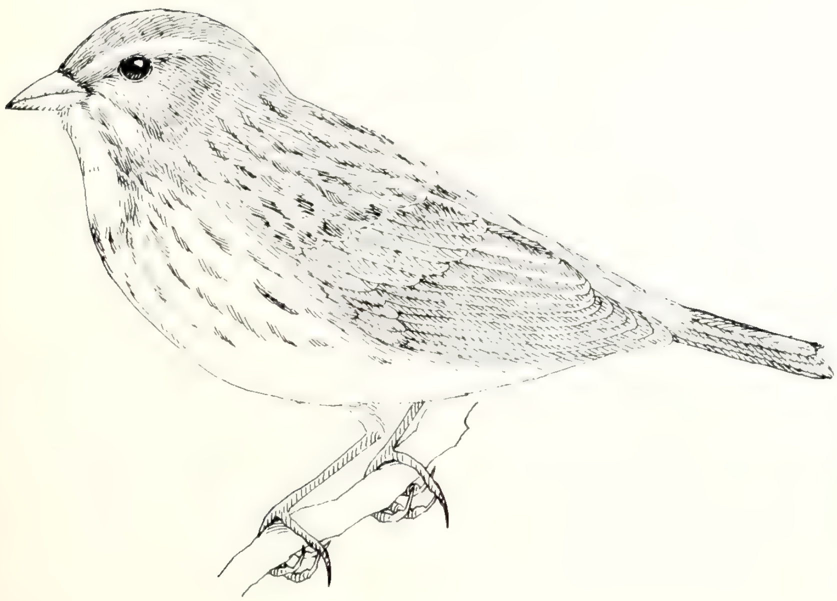
BREEDING: Apparently does not breed in the western Sierran zone.

TERRITORY/HOME RANGE: In Georgia, Norris (1960) reported a short-term (1 week) winter home range of 8 acres (3.2 ha). Data on breeding territory not applicable in the western Sierran zone.

FOOD HABITS: Eats insects and seeds obtained from the ground.

OTHER:

REFERENCES: Grinnell and Miller 1944, Bent 1968, Welsh 1975.



Grasshopper Sparrow

B194 (*Ammodramus savannarum*)

STATUS: No official listed status; on the 1978 Audubon Society Blue List. Rare summer resident at low elevations.

DISTRIBUTION/HABITAT: Breeds in grasslands and early successional stages, if sufficient grasses, up to ponderosa pine and black oak types. Irregularly distributed in California, with abundance varying from year-to-year. Probably winters below the 1000 ft (305 m) contour line set as lower limit of area included in this document.

SPECIAL HABITAT REQUIREMENTS:

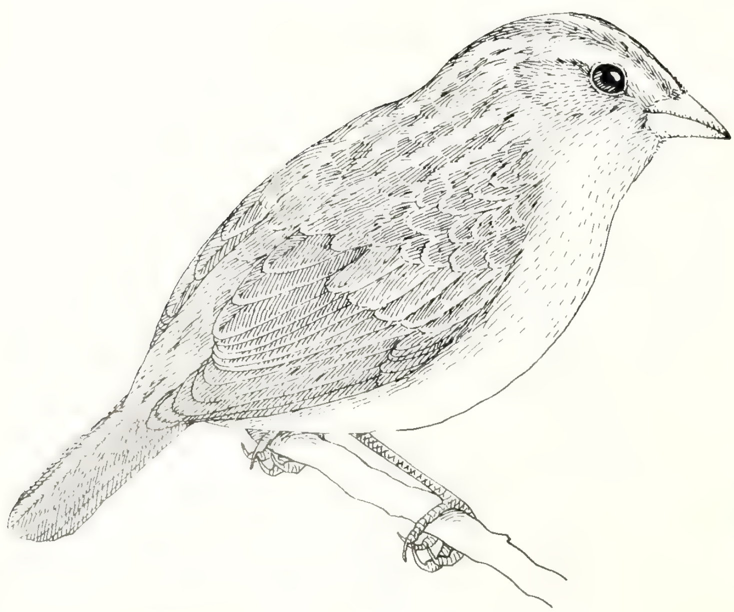
BREEDING: Breeds from late April to late June, with peak from mid-May to mid-June. Nests sunken in slight depressions in ground, hidden at base of clumps of grass or other cover. Most clutches contain 4 or 5 eggs.

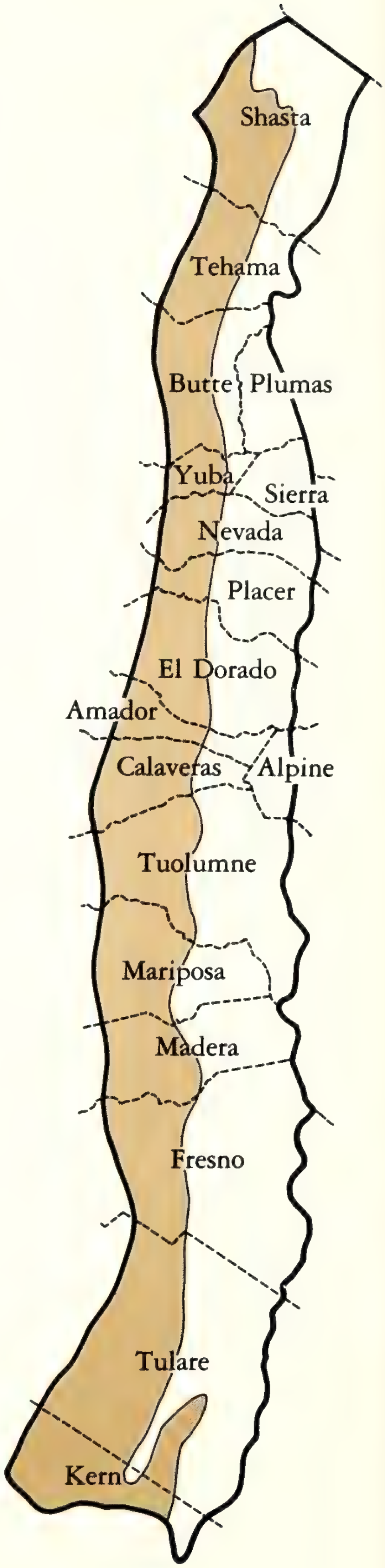
TERRITORY/HOME RANGE: No data on home range. In Wisconsin, territory size ranged from 0.8 to 3.2 acres (0.3 to 1.3 ha), with mean of 2 acres (0.8 ha) (Wiens 1973).

FOOD HABITS: Feeds mainly on insects, especially Orthopterans where abundant. Searches for food on ground, and sometimes scratches in litter.

OTHER:

REFERENCES: Grinnell and Miller 1944, Bent 1968, Tramontano 1971.





Vesper Sparrow

B195 *(Pooecetes gramineus)*

STATUS: No official listed status. Rare fall and winter visitor to lower elevations, only rarely at higher elevations in late summer and fall.

DISTRIBUTION/HABITAT: Frequents grasslands and early successional stages lacking shrubs.

SPECIAL HABITAT REQUIREMENTS:

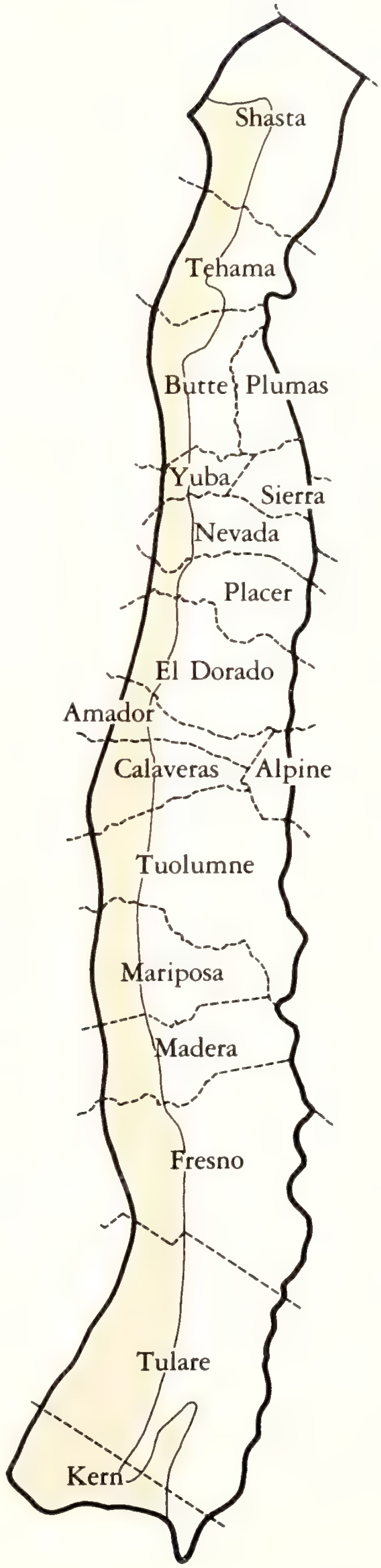
BREEDING: Does not breed in the western Sierran zone.

TERRITORY/HOME RANGE: Not applicable.

FOOD HABITS: Feeds on seeds, insects, and spiders. Feeds on ground and also gleans grass surfaces.

OTHER:

REFERENCES: Grinnell and Miller 1944, Bent 1968, Best 1972.



Lark Sparrow

B196 (*Chondestes grammacus*)

STATUS: No official listed status. Fairly common resident.

DISTRIBUTION/HABITAT: Breeds from blue oak savannahs up to ponderosa pine belt; generally prefers sites with scattered shrubs, or trees, or both.

SPECIAL HABITAT REQUIREMENTS: Shrubs/grass-forbs.

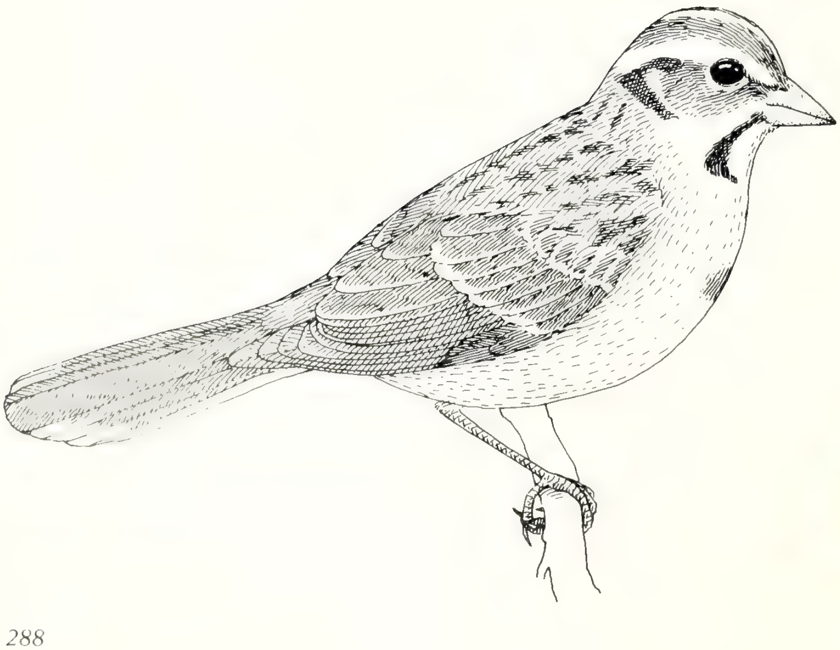
BREEDING: Breeds from late April to early July, with peak from mid-May to late June. Nests in depressions on ground, near clump of grass, or in low shrub. Most clutches contain 4 or 5 eggs.

TERRITORY/HOME RANGE: Fitch (1958) reported two territories at 3.4 and 8.8 acres (1.4 and 3.6 ha); he also reported summer range of one pair at 15 acres (6.1 ha). Defense of space strongest during courtship period (Bent 1968).

FOOD HABITS: Eats seeds of annuals and variety of insects. Forages on ground, prefers areas with plant litter; also gleans shrubs and small trees.

OTHER:

REFERENCES: Grinnell and Miller 1944, Bent 1968, Tramontano 1971.



Rufous-crowned Sparrow

B197 *(Aimophila ruficeps)*

STATUS: No official listed status. Uncommon resident.

DISTRIBUTION/HABITAT: Breeds in shrublands of blue oak savannahs, digger pine-oak woodlands, and especially chaparral zone. Some late summer and fall movement upslope into ponderosa pine forests. Seen at 4000 ft (1220 m) in Yosemite Valley (Gaines 1977).

SPECIAL HABITAT REQUIREMENTS: Shrubs/grass-forbs.

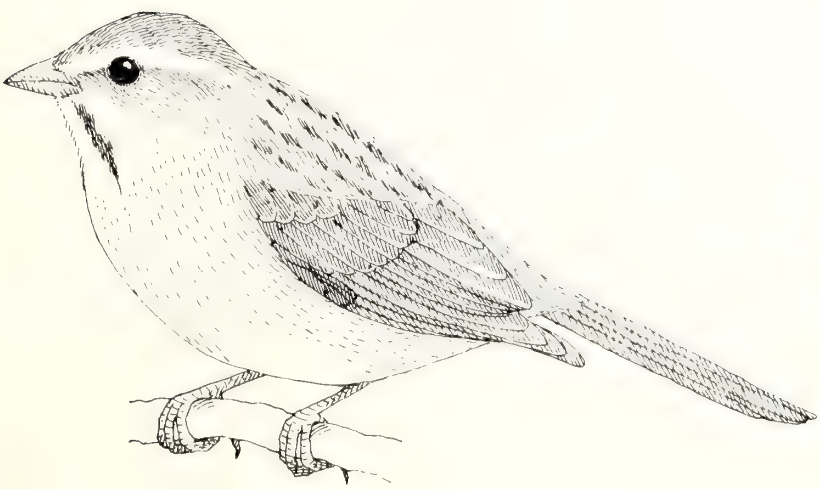
BREEDING: Breeds from mid-April to late June, with peak from early May to mid-June. Nests always on ground in grassy area, usually at base of shrub. Clutch size from 2 to 4, with mean of 3.

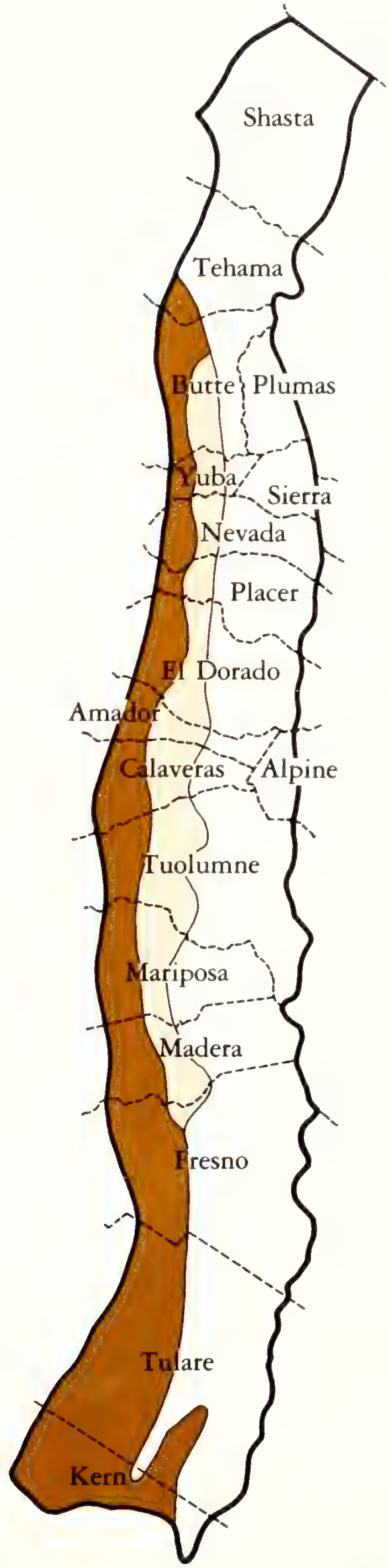
TERRITORY/HOME RANGE: No data on home range. In Southern California, 14 territories ranged from 1 to 3.8 acres (0.4 to 1.5 ha), with mean of 2.2 acres (0.9 ha) (Bent 1968).

FOOD HABITS: Obtains insects and various seeds by searching on ground and among grasses, or by gleaning from foliage of live oaks.

OTHER: A gregarious species; reported as semicolonial nester.

REFERENCES: Grinnell and Storer 1924, Grinnell and Miller 1944, Bent 1968.





Black-throated Sparrow

B198 *(Amphispiza bilineata)*

STATUS: No official listed status. Rare summer resident along Kern River; accidental in other areas in the Sierra Nevada.

DISTRIBUTION/HABITAT: Found in spring and summer in chaparral type, where it breeds. A few fall records in chaparral habitats in the northern Sierra Nevada.

SPECIAL HABITAT REQUIREMENTS:

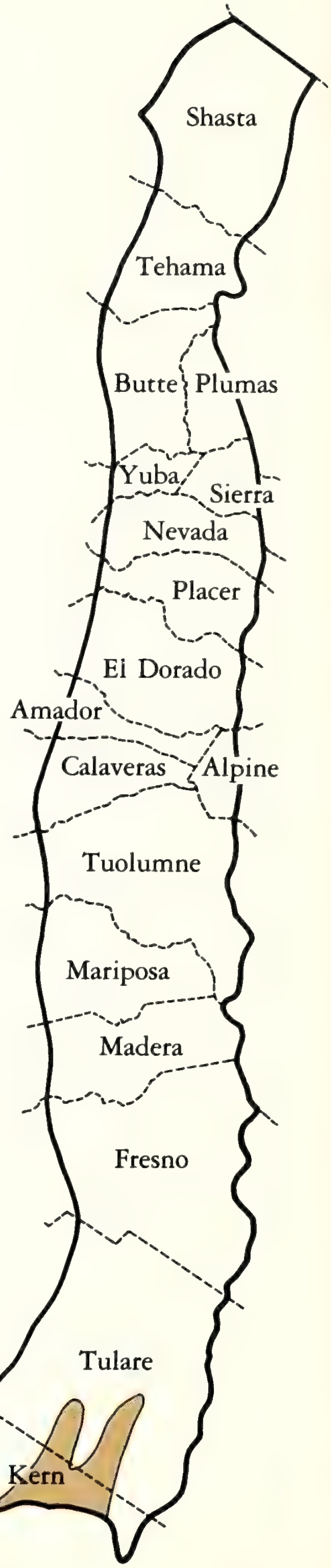
BREEDING: Breeds from mid-April to late June, with peak from late April to early June. Nests usually well concealed near ground in small shrub. Clutch size usually 3 or 4.

TERRITORY/HOME RANGE: Heckenlively (1967) reported New Mexico territories as about 394 to 492 ft ("about 120 to 150 meters") in diameter. Linsdale (1938) noted one pair apparently stayed in open area of about 1.4 acres (0.6 ha).

FOOD HABITS: Eats seeds and foliage; takes insects during nesting period. Feeds on ground and in grasses, forbs, and low shrubs. Sometimes hawks aerial insects.

OTHER:

REFERENCES: Grinnell and Miller 1944, Bent 1968, Tramontano 1971.



Sage Sparrow

B199 *(Amphispiza belli)*

STATUS: No official listed status. Common resident in central and southern areas.

DISTRIBUTION/HABITAT: Confined to chaparral vegetation; breeds only in dense, continuous stands of shrubs. In late summer and fall, usually moves upslope.

SPECIAL HABITAT REQUIREMENTS: Shrubs/grass-forbs.

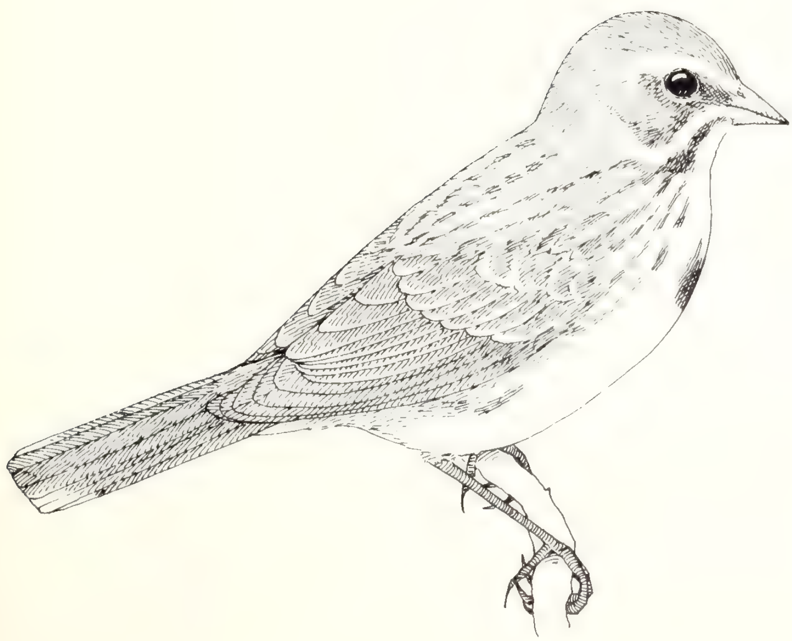
BREEDING: Breeds from early April to mid-June, with peak from late April to late May. Nests on or near ground, under overhanging shrub; *Artemisia* often used when available. Clutch averages 4.

TERRITORY/HOME RANGE: No data on home range. In Tehama County, territories about 150 ft (46 m) apart (Bent 1968).

FOOD HABITS: Eats insects, seeds, and succulent vegetation; may be sufficient to provide water needs. Gleans food from ground and low shrubs.

OTHER:

REFERENCES: Grinnell and Miller 1944, Sumner and Dixon 1953, Bent 1968.



Dark-eyed Junco

B200 *(Junco hyemalis)*

STATUS: No official listed status. Common to abundant summer resident at middle to high elevations; abundant winter resident at low elevations.

DISTRIBUTION/HABITAT: Breeds in timbered habitats from ponderosa pine and black oak woodland types upslope through lodgepole pine forests. Prefers areas with low percent canopy coverage. Frequents forest edges, but not confined to them. In fall and winter, moves downslope; abundant from annual grasslands up to ponderosa pine and black oak woodland zone.

SPECIAL HABITAT REQUIREMENTS: Shrubs/grass-forbs.

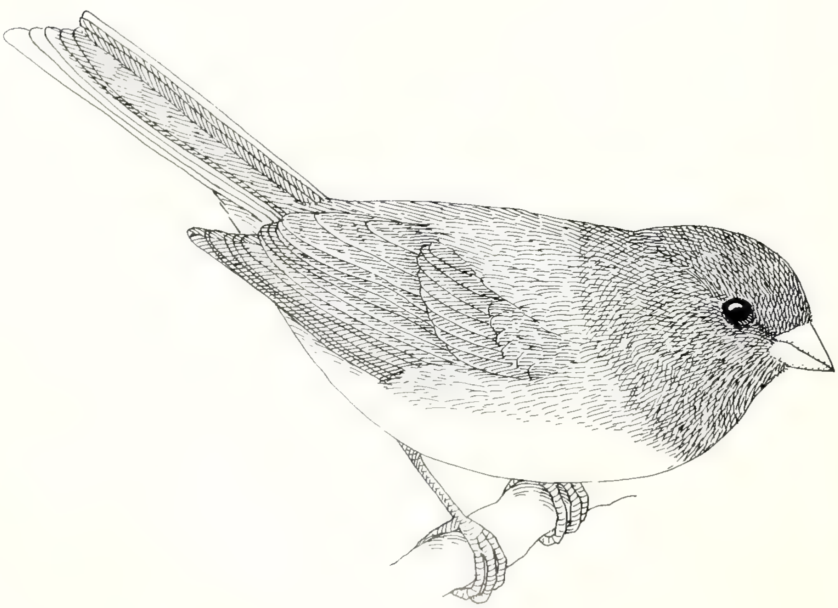
BREEDING: Breeds from early May to mid-August, with peak from early June to late July. Nests usually on ground, well concealed beneath grasses, shrubs, fallen logs, or in rock crevices; water usually nearby. Clutch size from 3 to 5, with mean of 4.

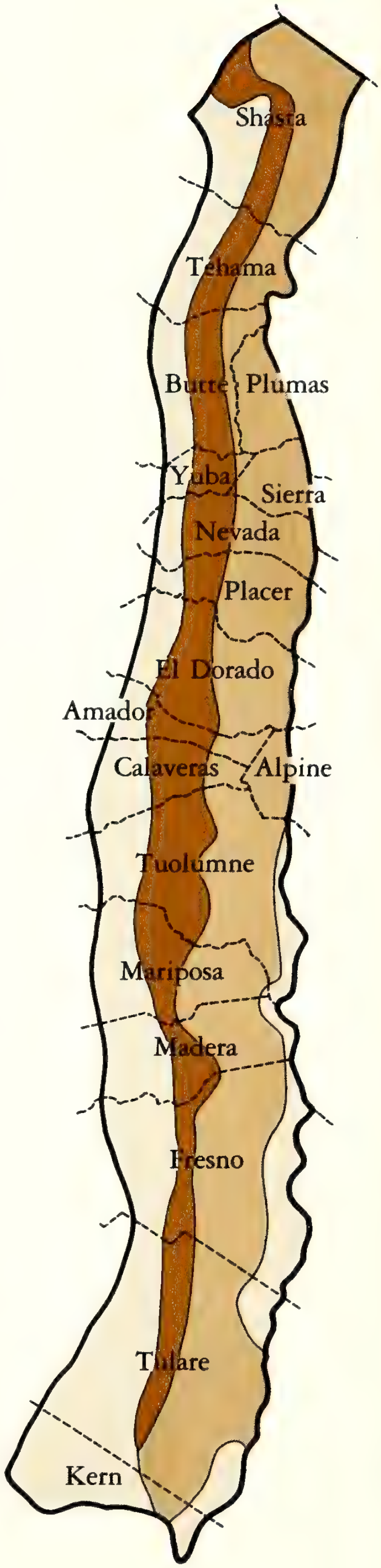
TERRITORY/HOME RANGE: In Kansas, winter home range averaged 26 acres (10.5 ha) for males and 13 acres (5.3 ha) for females (Fitch 1958). In New York, Bent (1968) recorded territories as "casually" estimated at 2 to 3 acres (0.8 to 1.2 ha).

FOOD HABITS: Eats arthropods, various seeds, and some fruit. Feeds mostly on ground in forests and meadows, also gleans foliage of shrubs and small trees, and hawks aerial insects. During nonbreeding period, typically feeds in flocks, often with white-crowned and golden-crowned sparrows.

OTHER: One of most abundant and most easily recognized species in timbered sections of the Sierra Nevada. Formerly known as Oregon junco.

REFERENCES: Williams 1942, Sumner and Dixon 1953, White 1973.





Chipping Sparrow

B201 *(Spizella passerina)*

STATUS: No official listed status. Fairly common spring migrant and summer resident.

DISTRIBUTION/HABITAT: Breeds from chaparral zone up to lodgepole pine forests; prefers stands with low to intermediate percent canopy cover, and areas with bare ground or sparse grass.

SPECIAL HABITAT REQUIREMENTS:

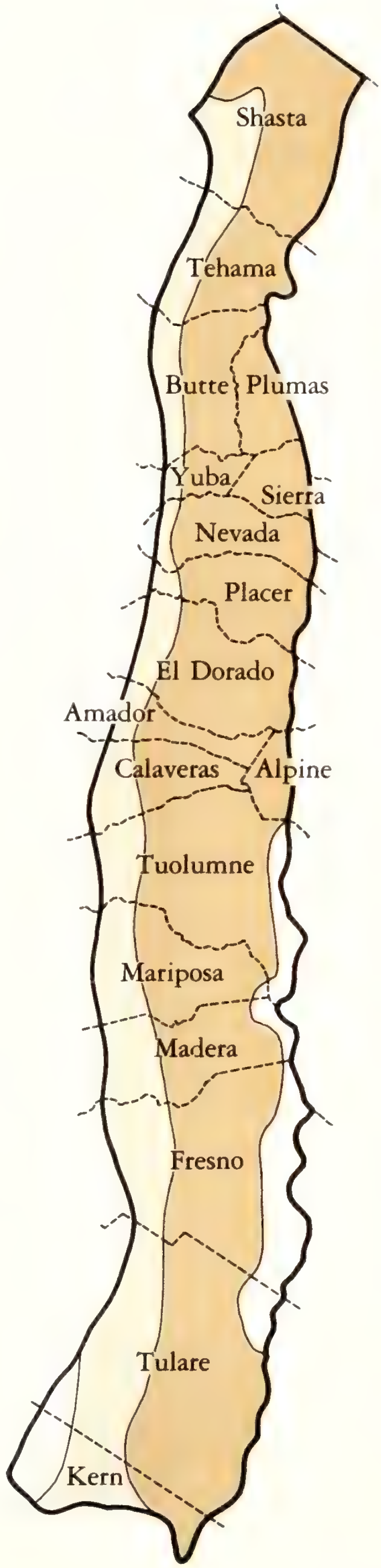
BREEDING: Breeds from early April to mid-July, with peak from mid-May to late June. Nests near outer end of branch, usually of conifer, from 5 to 40 ft (1.5 to 12 m) above ground. Clutch size from 3 to 5, with mean of 4.

TERRITORY/HOME RANGE: No data on home range. In an Arizona piñon-juniper-ponderosa pine ectone, Laudenslayer and Balda (1976) reported mean territory size as 6.9 acres (2.8 ha). A pair in South Carolina defended 7.6 acres (3.1 ha) while nest building but only 2.7 acres (1.1 ha) while feeding young (Odum and Kuenzler 1955).

FOOD HABITS: Insects and weed seeds gleaned from ground and foliage; insects rarely hawked from air.

OTHER:

REFERENCES: Grinnell and Storer 1924, Grinnell *et al.* 1930, Bent 1968.



Brewer's Sparrow

B202 *(Spizella breweri)*

STATUS: No official listed status. Rare summer resident and breeder.

DISTRIBUTION/HABITAT: Reported rarely in chaparral and shrub successional stages from ponderosa pine to the lodgepole pine forests. Only one confirmed nesting record (Grinnell *et al.* 1930), though probably nests in Kern River canyon (Sumner and Dixon 1953), and in Placer County (D. Gaines, pers. commun.). Often associated with *Artemisia*.

SPECIAL HABITAT REQUIREMENTS:

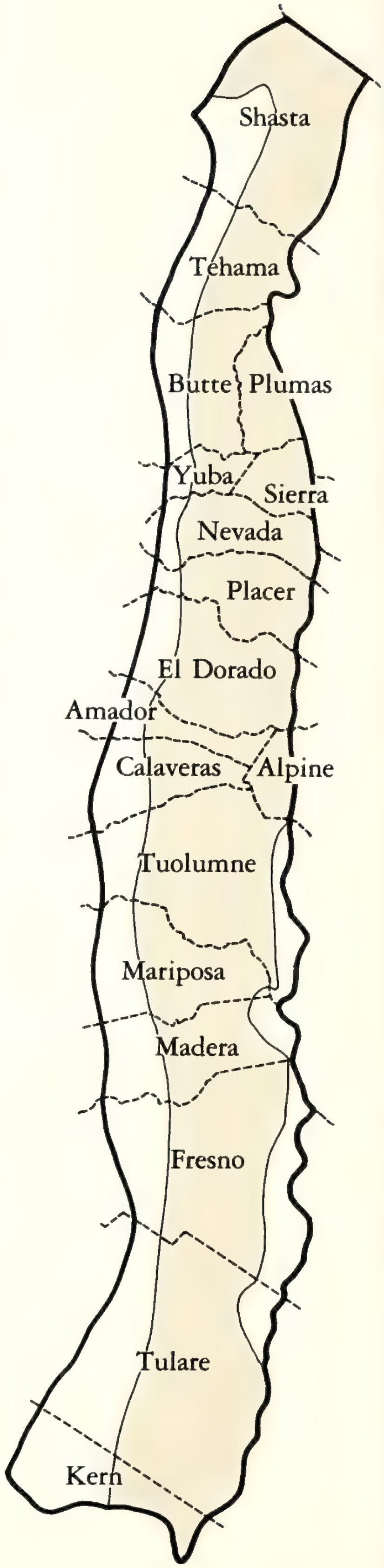
BREEDING: Breeds from late April to early July, with peak from mid-May to late June. Nests in small shrub in well-concealed situation, usually on south-facing slopes. Nest height less than 3 ft (0.9 m). Clutch size from 3 to 5, with mean of 4.

TERRITORY/HOME RANGE: No data on territory or home range.

FOOD HABITS: Eats primarily weed seeds, though some insects are taken. Picks up seeds from ground and gleans low foliage.

OTHER:

REFERENCES: Grinnell and Storer 1924, Grinnell and Miller 1944, Bent 1968.



Black-chinned Sparrow

B203 *(Spizella atrogularis)*

STATUS: No official listed status. Uncommon summer resident in suitable habitat.

DISTRIBUTION/HABITAT: Restricted to dense shrub habitats, particularly in chaparral zone, but also in early successional stages of ponderosa pine, black oak woodland, and mixed-conifer zones. Prefers dry, south-facing slopes, usually associated with *Adenostoma, Artemisia, Ceanothus,* and *Arctostaphylos.*

SPECIAL HABITAT REQUIREMENTS: Shrubs/grass-forbs.

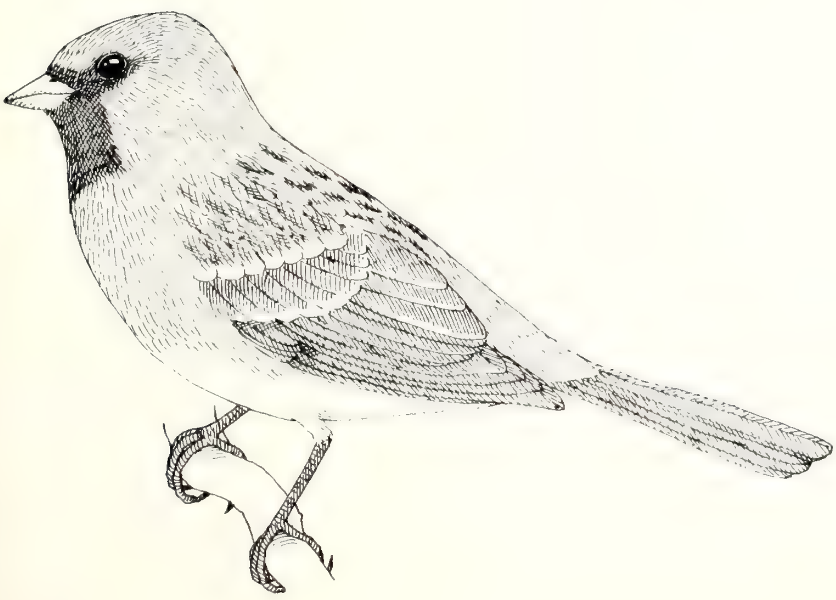
BREEDING: Breeds from mid-April to mid-July, with peak from mid-May to late June. Nest concealed in low bush. Clutch size from 2 to 4, with mean of 3.

TERRITORY/HOME RANGE: No data available.

FOOD HABITS: No data available.

OTHER:

REFERENCES: Grinnell and Miller 1944, Bent 1968.



White-crowned Sparrow

B204 *(Zonotrichia leucophrys)*

STATUS: No official listed status. Common to abundant in preferred habitat.

DISTRIBUTION/HABITAT: Breeds in early successional stages of lodgepole pine forests and alpine meadows, primarily along edges of meadows, streams, or lakes, usually using willow or small lodgepole pine for cover and perching. Our breeding population leaves the Seirra Nevada in September. Wintering birds arrive from Canada and Alsaka in September, found at all elevations below lodgepole belt in fall, moving down to foothills and valley floor for winter. Prefers fairly open areas with patches of shrubs or thickets.

SPECIAL HABITAT REQUIREMENTS: Shrubs/grass-forbs; water for breeding.

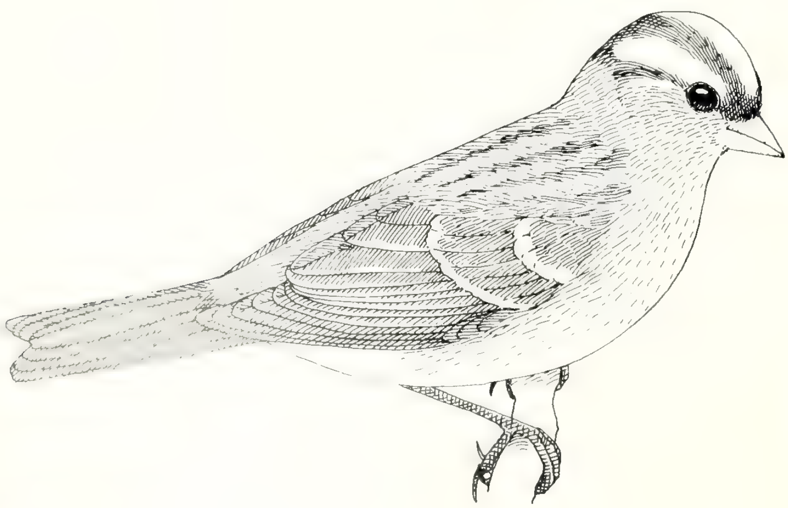
BREEDING: Breeds from late May to late August, with peak from late June to early August. Nests on ground at base of bush, or in low branches of shrub, willow, or small conifer. Height ranges from 0 to 5 ft (0 to 1.5 m) above ground.

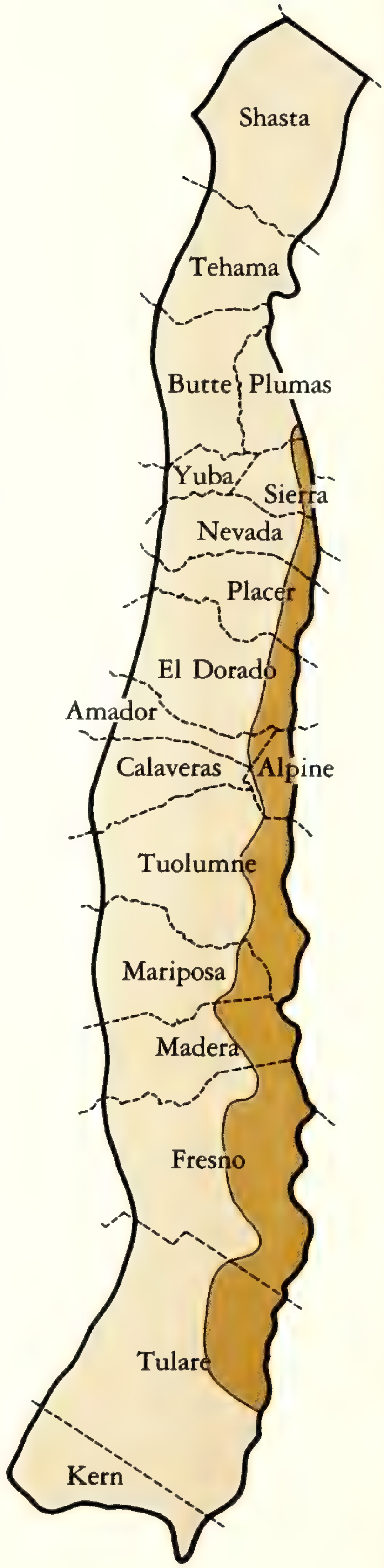
TERRITORY/HOME RANGE: Morton *et al.* (1972) reported defended areas around nest of 0.4 to about 2 acres (0.15 to about 0.8 ha), stating that the pair may occupy an area as large as 3.7 to 4.9 acres (1.5 to 2.0 ha)—a possible estimate of home range. These estimates come from Sierran birds near Tioga Pass. Ralph and Pearson (1971) reported territory sizes of birds in Marin County ranging from 0.15 to 1.5 acres (0.06 to 0.59 ha) with average of 0.6 acre (0.24 ha). Price (1931) reported winter flock home range as 15 to 20 acres (6.1 to 8.1 ha) in San Mateo County, while Blanchard (1941) found winter home ranges in coastal California of 0.9 to 1.7 acres (0.4 to 0.7 ha).

FOOD HABITS: Eats mostly seeds of grasses and forbs, also eats green shoots, berries, and insects. Gleans food from bare ground or grassy areas near shrubs. Usually scratches the ground in search of food.

OTHER:

REFERENCES: Blanchard 1941, Blanchard and Erickson 1949, DeWolfe and DeWolfe 1962, Morton 1967, Morton *et al.* 1972.





Golden-crowned Sparrow

B205 *(Zonotrichia atricapilla)*

STATUS: No official listed status. Common winter visitor.

DISTRIBUTION/HABITAT: Widespread; prefers interrupted brushlands, such as streamside thickets and chaparral with open patches. Prefers moister sites than congener, the white-crowned sparrow. Found sparingly in early fall as high as red fir zone, but moves down to chaparral, digger pine-oak, and blue oak zones for winter and spring.

SPECIAL HABITAT REQUIREMENTS:

BREEDING: Does not nest in the western Sierran range.

TERRITORY/HOME RANGE: Winter home range size at San Jose was about 3 acres (1.2 ha) (Robertson 1957). In San Mateo County, Price (1931) reported winter home range of flocks as 15 to 20 acres (6.1 to 8.1 ha).

FOOD HABITS: Eats mainly seeds, shoots, buds, and flowers of grasses and forbs. Scratches in ground litter, picks seeds, and gleans items, mainly from ground.

OTHER:

REFERENCES: Robertson 1957, Bent 1968, Davis 1973.

Fox Sparrow

B206 *(Passerella iliaca)*

STATUS: No official listed status. Common resident in the western Sierran zone.

DISTRIBUTION/HABITAT: Breeds from chaparral zone up to lodgepole pine forests; prefers sites with considerable shrub layer. In fall and winter, found in blue oak savannahs and digger pine-oak woodlands.

SPECIAL HABITAT REQUIREMENTS: Dense shrubs.

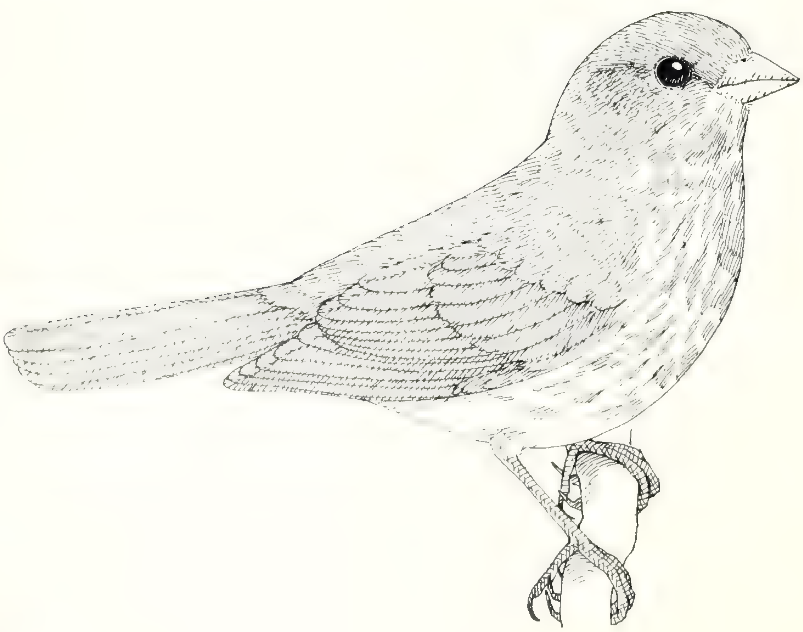
BREEDING: Breeds from mid-May to early August, with peak from early June to late July. Nests placed in dense shrubs, or occasionally on the ground. Nests range in height from 0 to 6 ft (0 to 1.8 m). Mean clutch size 3 or 4, with range from 3 to 5.

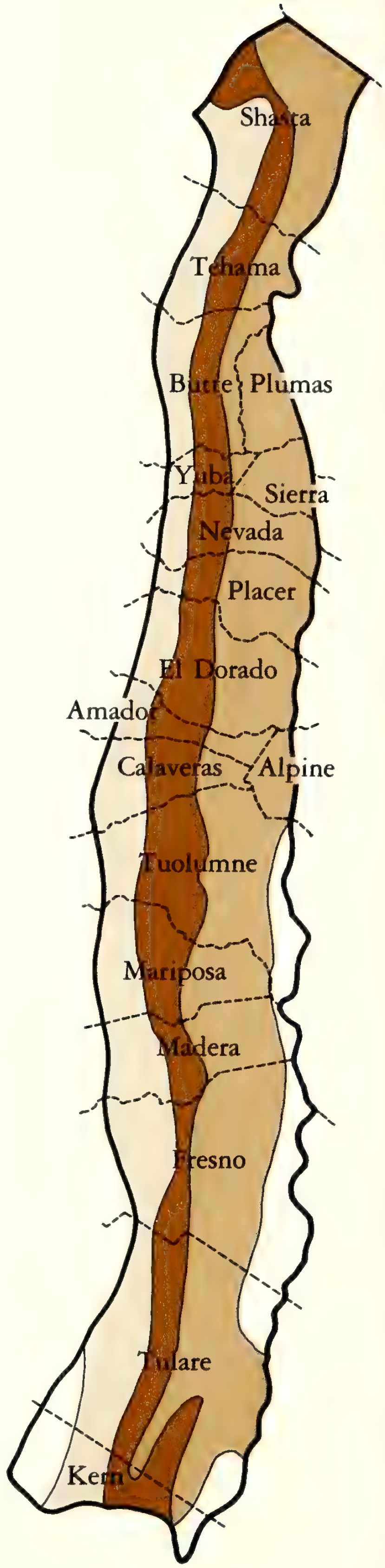
TERRITORY/HOME RANGE: No data on home range or territory size. Six pairs reported on 6.5 acres (2.6 ha) in Lassen County (Linsdale 1928).

FOOD HABITS: Feeds mainly on insects in summer, and seeds in winter. Feeds on the ground, scratching in litter under shrubs and in weed patches.

OTHER: Nesting form leaves the Sierra Nevada for winter, has grayish head and back. Wintering birds migrate from further north, have browner heads and backs.

REFERENCES: Grinnell and Storer 1924, Bent 1968, Gaines 1977.





Lincoln's Sparrow

B207 *(Melospiza lincolnii)*

STATUS: No official listed status. Fairly common summer resident and migrant at high elevations, and winter resident at low elevations.

DISTRIBUTION/HABITAT: Nests usually in wet meadows or lakeside and streamside thickets at middle to high elevations. Breeding birds generally leave the Sierra Nevada by September; northern migrants come into riparian and lakeside habitats in the lowland oak and digger pine-oak types.

SPECIAL HABITAT REQUIREMENTS: Dense shrubs; ponds, lakes, streams, rivers, or wet meadows.

BREEDING: Breeds from mid-May to late July, with peak from late May to late June. Nest placed in a depression on the ground, well concealed by dense shrubbery. Clutch size from 3 to 6, with mean of 4.

TERRITORY/HOME RANGE: No data on home range. In Ontario, territory size appeared to be about 1 acre (0.4 ha) (Bent 1968).

FOOD HABITS: Feeds mainly on insects and seeds taken from ground and air. Scratches in ground litter and flycatches from the ground.

OTHER:

REFERENCES: Grinnell and Storer 1924, Grinnell and Miller 1944, Bent 1968.

Song Sparrow

B208 (*Melospiza melodia*)

STATUS: No official listed status. Fairly common resident at low elevations; limited numbers at mid-elevations in summer.

DISTRIBUTION/HABITAT: Breeds in low, dense vegetation along streams, ponds and marshes, and wet meadows from blue oak savannahs up to ponderosa pine and black oak woodland zone. Found in winter in similar habitats, but generally below about 2000 ft (610 m).

SPECIAL HABITAT REQUIREMENTS: Dense shrubs; ponds, lakes, streams, rivers, or wet meadows.

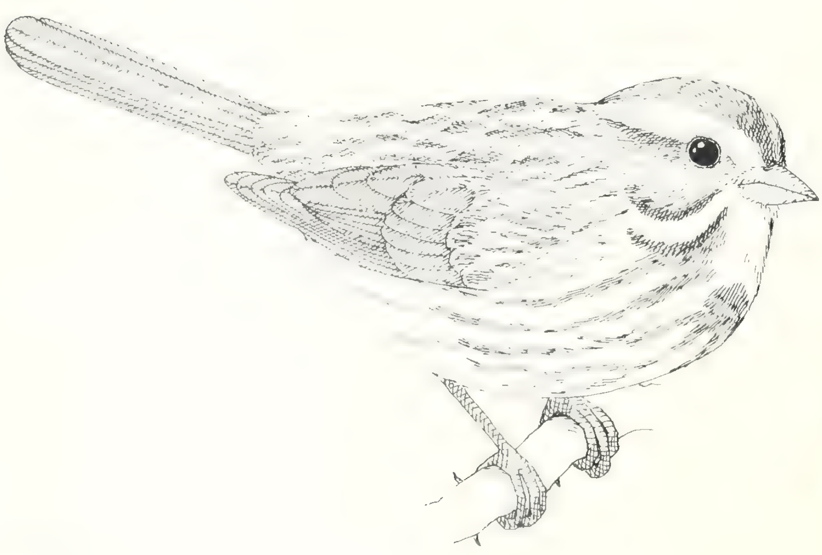
BREEDING: Breeds from late April to early July, with peak from late May to late June. Nest situated in low, dense shrubbery in wet meadows or streamside thickets; must have concealment and a secure support. Nest height ranges from 0 to 12 ft (0 to 3.7 m). Clutch size from 3 to 6, with mean of 4.

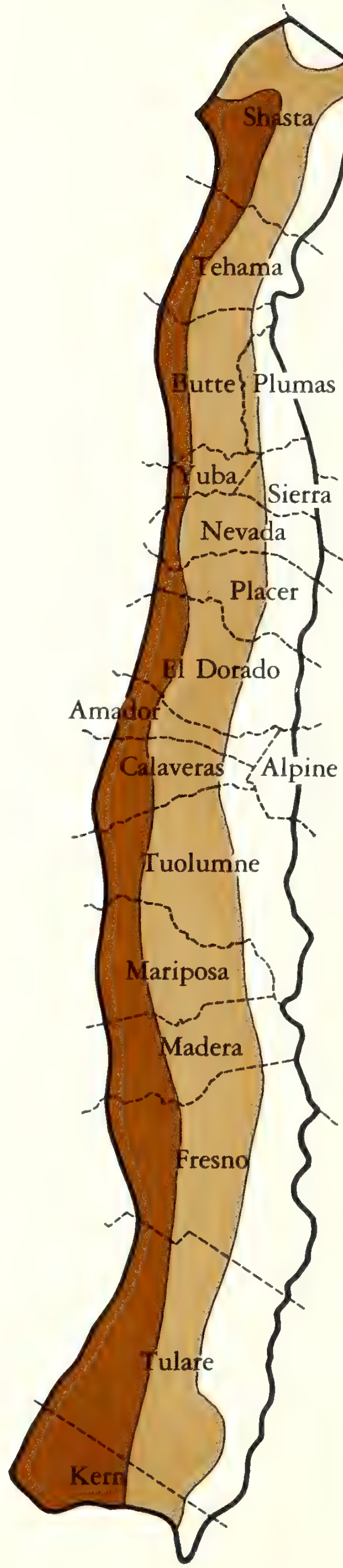
TERRITORY/HOME RANGE: Territories in Ohio ranged from 0.5 to 1.5 acres (0.2 to 0.6 ha), averaging 0.7 acre (0.3 ha) (Nice 1943). Territory size in salt marshes of Contra Costa County averaged about 4350 ft^2 (400 m^2) in a year of high density (Johnston 1956). Home range data scanty; a single winter home range in New York reported at 1.4 acres (0.6 ha) (Butts 1927); a single winter home range in Kansas reported at 8.9 acres (3.6 ha), and an average based on 29 poorly studied birds of about 6.8 acres (2.8 ha) (Fitch 1958).

FOOD HABITS: Eats insects, weed seeds, some fruit, and berries. Forages on ground, scratching in litter; gleans foliage low in thickets; and rarely hawks aerial insects.

OTHER: Some evidence suggests recent and slight increase in abundance and distribution on west slopes of the Sierra Nevada.

REFERENCES: Grinnell and Storer 1924; Nice 1937, 1943; Bent 1968.





Rare Species

Observations of the following 57 species of birds in the western Sierra Nevada have been documented five or fewer times:

Common Loon
(Gavia immer)
Arctic Loon
(Gavia arctica)
Horned Grebe
(Podiceps auritus)
White Pelican[1]
(Pelecanus occidentalis)
Double-crested Cormorant
(Phalacrocorax auritus)
Great Egret
(Casmerodius albus)
Snowy Egret
(Egretta thula)
American Bittern
(Botaurus lentiginosus)
Gadwall
(Anas strepera)
Blue-winged Teal
(Anas discors)
Common Goldeneye
(Bucephala clangula)
White-winged Scoter
(Melanitta deglandi)
Surf Scoter
(Melanitta perspicillata)
Rough-legged Hawk
(Buteo lagopus)
Ferruginous Hawk
(Buteo regalis)
Sage Grouse
(Centrocercus urophasianus)
Bobwhite[2]
(Colinus virginianus)
Sandhill Crane[1]
(Grus canadensis)
Sora
(Porzana carolina)
Solitary Sandpiper
(Tringa solitaria)
Wandering Tattler
(Heteroscelus incanus)
Willet
(Catoptrophorus semipalmatus)
Greater Yellowlegs
(Tringa melanoleuca)
Black-necked Stilt
(Himantopus mexicanus)
Northern Phalarope
(Lobipes lobatus)
Parasitic Jaeger
(Stercorarius parasiticus)
Forster's Tern
(Sterna forsteri)
Caspian Tern
(Hydroprogne caspia)
Rock Dove[3]
(Columba livia)
Yellow-billed Cuckoo[4]
(Coccyzus americanus)
Lesser Nighthawk
(Chordeiles acutipennis)
Costa's Hummingbird
(Calypte costae)
Ladder-backed Woodpecker[5]
(Picoides scalaris)
Wied's Crested Flycatcher
(Myiarchus tyrannulus)
Gray Flycatcher
(Empidonax wrightii)
Bank Swallow
(Riparia riparia)
Purple Martin
(Progne subis)
Cactus Wren[5]
(Campylorhynchus brunneicapillus)
Sage Thrasher
(Oreoscoptes montanus)
Bohemian Waxwing
(Bombycilla garrulus)
Northern Shrike
(Lanius excubitor)
Black-and-white Warbler
(Mniotilta varia)
Virginia's Warbler
(Vermivora virginiae)
Magnolia Warbler
(Dendroica magnolia)
Blackburnian Warbler
(Dendroica fusca)
Ovenbird
(Seiurus aurocapillus)
Connecticut Warbler
(Oporonis agilis)
American Redstart
(Setophaga ruticilla)
Hooded Oriole
(Icterus cucullatus)
Scott's Oriole[5]
(Icterus parisorum)
Rusty Blackbird
(Euphagus carolinus)
Summer Tanager
(Piranga flava)
Rose-breasted Grosbeak
(Pheucticus ludovicianus)
Indigo Bunting
(Passerina cyanea)
Gray-headed Junco[6]
(Junco caniceps)
Harris' Sparrow
(Zonotrichia querula)
White-throated Sparrow
(Zonotrichia albicollis)

[1]Flocks overhead often seen, but seldom land.
[2]Introduced species; uncertain whether established.
[3]Small populations in a few low-elevation communities, such as Auburn, Placer County (R. Stallcup, pers. commun., May, 1977).
[4]Found only in riparian woodland along Kern River, Kern County; breeds.
[5]Found only in Joshua tree woodland along Kern River, Kern County; probably breeds.
[6]One breeding record, in Mineral King area, Tulare County (Stallcup and Greenberg 1974).

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Mammals

Marshall White, Reginald H. Barrett, Allan S. Boss, Thomas F. Newman, Thomas J. Rahn, and Daniel F. Williams

This chapter offers information on the status, distribution by habitat, and basic life history of 94 species of mammals inhabiting the western Sierra Nevada. These data were drawn primarily from the literature, much of which consists of reports of studies conducted in areas outside of the Sierra Nevada. Additional information was provided by the field experience of the professional mammalogists involved with the project.

Determinations made about habitat selection, food habits, breeding season, and distribution are generally based upon limited studies or even general impressions of the species elsewhere. For a few species, no life history data were available. For most others, there were few or no data on habitat selection by successional stage or canopy cover, or on microhabitat requirements within the more general habitats of the Sierra Nevada. Life history information on most of the species of bats is especially scanty, and the determinations made beyond are largely unsupported by field studies. Thus, in large part, this work should be viewed as the starting point. It presents a series of hypotheses about habitat requirements that must ultimately be tested by detailed field studies.

Few mammal species of the western Sierra Nevada have "official listed status" (the wolverine and mountain sheep are designated as Rare by the State of California). Some other species are, however, fully protected, and may not be killed or captured except under special permit from the California Department of Fish and Game. Several species are classified by the California Department of Fish and Game as game species or as furbearers, and their capture is regulated by license, season, bag limits, and locality. Finally, those species without special status (above), which include the majority of small, nongame mammals, may be captured only under authority of a special scientific collecting permit or a hunting license.

The scientific and common names for the mammals are those of Jones *et al.* (1975). Departures from that list represent taxonomic changes made since its publication. The species are arranged in phylogenetic order and numbered in sequence, with the prefix "M", for purposes of internal cross-referencing and computer access coding.

Species List

M001 Opossum
Didelphis virginiana

M002 Mount Lyell Shrew
Sorex lyelli

M003 Vagrant Shrew
Sorex vagrans

M004 Dusky Shrew
Sorex monticolus

M005 Ornate Shrew
Sorex ornatus

M006 Water Shrew
Sorex palustris

M007 Trowbridge's Shrew
Sorex trowbridgii

M008 Shrew-mole
Neurotrichus gibbsii

M009 Broad-footed Mole
Scapanus latimanus

M010 Little Brown Myotis
Myotis lucifugus

M011 Yuma Myotis
Myotis yumanensis

M012 Long-eared Myotis
Myotis evotis

M013 Fringed Myotis
Myotis thysanodes

M014 Long-legged Myotis
Myotis volans

M015 California Myotis
Myotis californicus

M016 Small-footed Myotis
Myotis leibii

M017 Silver-haired Bat
Lasionycteris noctivagans

M018 Western Pipistrelle
Pipistrellus hesperus

M019 Big Brown Bat
Eptesicus fuscus

M020 Red Bat
Lasiurus borealis

M021 Hoary Bat
Lasiurus cinereus

M022 Spotted Bat
Euderma maculatum

M023 Townsend's Big-eared Bat
Plecotus townsendii

M024 Pallid Bat
Antrozous pallidus

M025 Brazilian Free-tailed Bat
Tadarida brasiliensis

M026 Pika
Ochotona princeps

M027 Brush Rabbit
Sylvilagus bachmani

M028 Desert Cottontail
Sylvilagus audubonii

M029 Snowshoe Hare
Lepus americanus

M030 White-tailed Jackrabbit
Lepus townsendii

M031 Black-tailed Jackrabbit
Lepus californicus

M032 Mountain Beaver
Aplodontia rufa

M033 Alpine Chipmunk
Eutamias alpinus

M034 Least Chipmunk
Eutamias minimus

M035 Yellow Pine Chipmunk
Eutamias amoenus

M036 Allen's Chipmunk
Eutamias senex

M037 Sonoma Chipmunk
Eutamias sonomae

M038 Merriam's Chipmunk
Eutamias merriami

M039 Long-eared Chipmunk
Eutamias quadrimaculatus

M040 Lodgepole Chipmunk
Eutamias speciosus

M041 Yellow-bellied Marmot
Marmota flaviventris

M042 Belding's Ground Squirrel
Spermophilus beldingi

M043 California Ground Squirrel
Spermophilus beecheyi

M044 Golden-mantled Ground Squirrel
Spermophilus lateralis

M045 Western Gray Squirrel
Sciurus griseus

M046 Douglas' Squirrel
Tamiasciurus douglasii

M047 Northern Flying Squirrel
Glaucomys sabrinus

M048 Botta's Pocket Gopher
Thomomys bottae

M049 Mountain Pocket Gopher
Thomomys monticola

M050 Little Pocket Mouse
Perognathus longimembris

M051 Great Basin Pocket Mouse
Perognathus parvus

M052 Yellow-eared Pocket Mouse
Perognathus xanthonotus

M053 California Pocket Mouse
Perognathus californicus

M054 Heermann's Kangaroo Rat
Dipodomys heermanni

M055 California Kangaroo Rat
Dipodomys californicus

M056 Beaver
Castor canadensis

M057 Western Harvest Mouse
Reithrodontomys megalotis

M058 California Mouse
Peromyscus californicus

M059 Deer Mouse
Peromyscus maniculatus

M060 Brush Mouse
Peromyscus boylii

M061 Piñon Mouse
Peromyscus truei

M062 Dusky-footed Woodrat
Neotoma fuscipes

M063 Bushy-tailed Woodrat
Neotoma cinerea

M064 Western Red-backed Vole
Clethrionomys occidentalis

M065 Heather Vole
Phenacomys intermedius

M066 Montane Vole
Microtus montanus

M067 California Vole
Microtus californicus

M068 Long-tailed Vole
Microtus longicaudus

M069 Muskrat
Ondatra zibethicus

M070 Western Jumping Mouse
Zapus princeps

M071 Porcupine
Erethizon dorsatum

M072 Coyote
Canis latrans

M073 Red Fox
Vulpes vulpes

M074 Gray Fox
Urocyon cinereoargenteus

M075 Black Bear
Ursus americanus

M076 Ringtail
Bassariscus astutus

M077 Raccoon
Procyon lotor

M078 Marten
Martes americana

M079 Fisher
Martes pennanti

M080 Ermine
Mustela erminea

M081 Long-tailed Weasel
Mustela frenata

M082 Mink
Mustela vison

M083 Wolverine
Gulo gulo

M084 Badger
Taxidea taxus

M085 Western Spotted Skunk
Spilogale gracilis

M086 Striped Skunk
Mephitis mephitis

M087 River Otter
Lutra canadensis

M088 Mountain Lion
Felis concolor

M089 Bobcat
Felis rufus

M090 Wild Horse
Equus caballus

M091 Wild Pig
Sus scrofa

M092 Wapiti
Cervus elaphus

M093 Mule Deer
Odocoileus hemionus

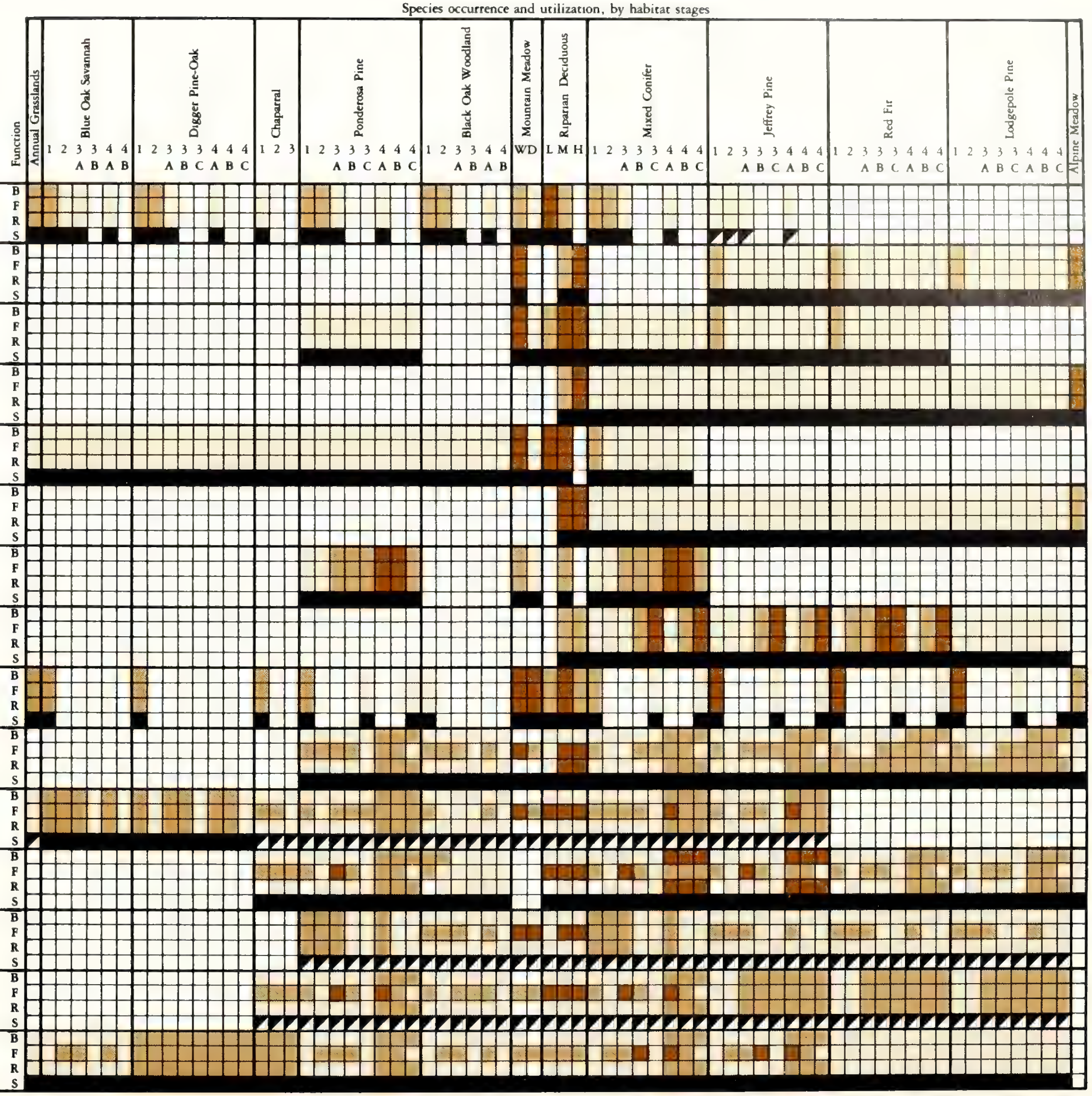
M094 Mountain Sheep
Ovis canadensis

LEGEND
Optimum Habitat (1)
Suitable Habitat (2)
Marginal Habitat (3)
Spring
Summer
Fall
Winter

For key to this matrix, see *figure 2*.

Species occurrence and utilization, by habitat stages

Code	Species	Special Habitat Requirements	Page
M001	Virginia Opossum		331
M002	Mt. Lyell Shrew	Moist soil	332
M003	Vagrant Shrew	Moist soil; stumps, logs, or litter	333
M004	Dusky Shrew	Moist soil; stumps, logs, or litter	334
M005	Ornate Shrew	Moist soil; stumps, logs, or litter	335
M006	Water Shrew	Clear, cold streams	336
M007	Trowbridge's Shrew	Stumps, logs, or litter	337
M008	Shrew-Mole	Friable soils; litter, rotting logs, or stumps	338
M009	Broad-footed Mole	Forest openings; moist, friable soil	339
M010	Little Brown Myotis	Snags; caves; permanent pools, ponds, or lakes	340
M011	Yuma Myotis	Permanent pools, ponds or lakes; caves, crevices, or snags	341
M012	Long-eared Myotis	Caves, snags, or trees; water	342
M013	Fringed Myotis	Caves or rock crevices; water	343
M014	Long-legged Myotis	Trees, snags, or crevices; water	344
M015	California Myotis	Crevices; water	345

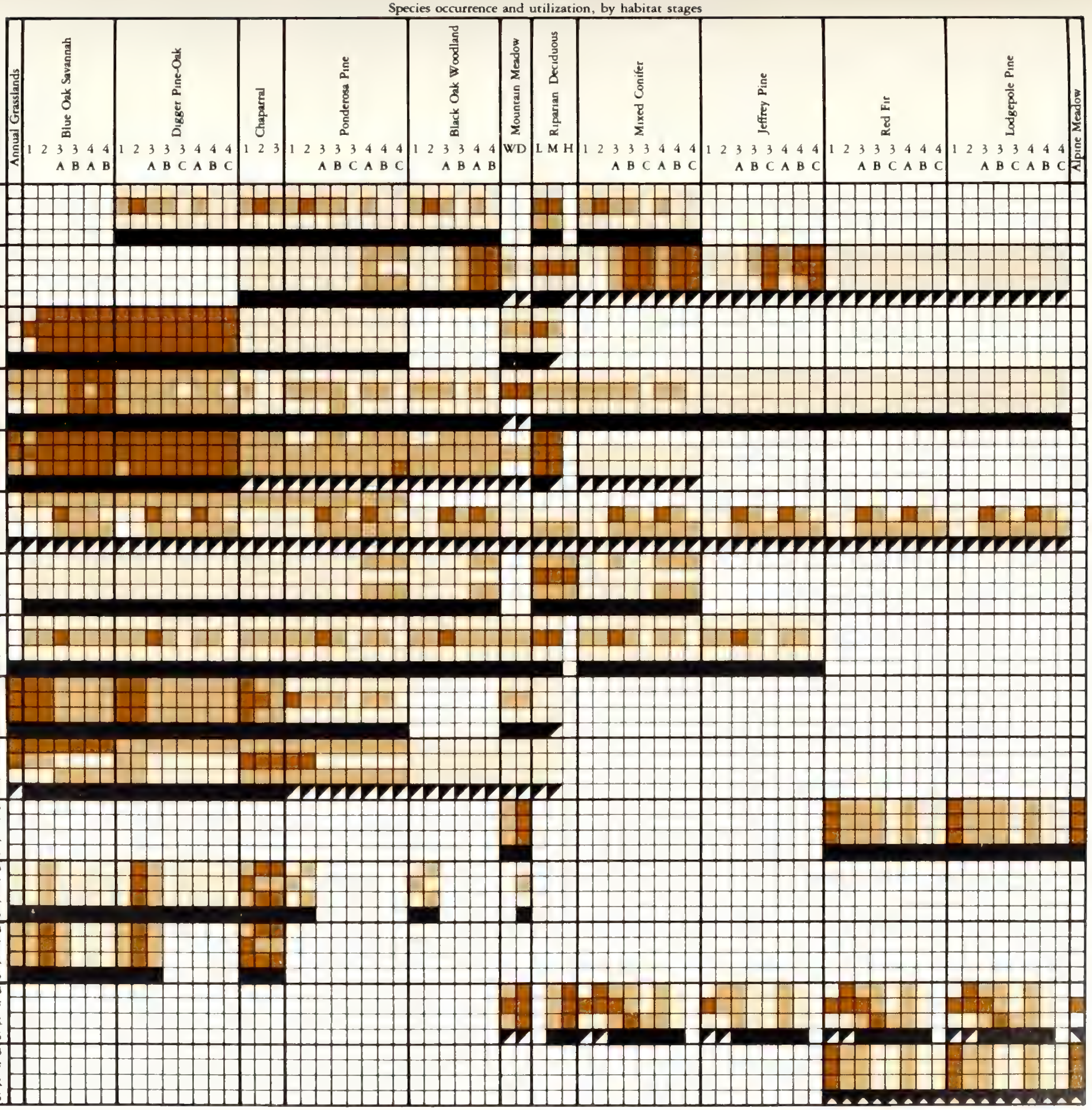


LEGEND
- Optimum Habitat (1)
- Suitable Habitat (2)
- Marginal Habitat (3)
- Spring
- Summer
- Fall
- Winter

For key to this matrix, see *figure 2*.

Species occurrence and utilization, by habitat stages

Code	Species	Special Habitat Requirements	Page	Function
M016	Small-footed Myotis	Caves, mines, or crevices; water	346	B F R S
M017	Silver-haired Bat	Trees or snags; water	347	B F R S
M018	Western Pipistrelle	Crevices; water	348	B F R S
M019	Big Brown Bat	Snags, caves, crevices, trees, or buildings; water	349	B F R S
M020	Red Bat	Snags; trees; water	350	B F R S
M021	Hoary Bat	Trees; water	351	B F R S
M022	Spotted Bat	Caves or crevices, ponds, lakes, or large pools in streams or rivers	352	B F R S
M023	Townsend's Big-eared Bat	Caves or crevices; low human disturbance	353	B F R S
M024	Pallid Bat	Caves, crevices, or buildings, water	354	B F R S
M025	Brazilian Free-tailed Bat	Crevices, buildings, or bridges, water	355	B F R S
M026	Pika	Talus, forest openings	356	B F R S
M027	Brush Rabbit	Shrubs/grass-forbs	357	B F R S
M028	Desert Cottontail	Shrubs/grass-forbs	358	B F R S
M029	Snowshoe Hare	Trees/shrubs; shrubs/grass-forbs, hollow logs	359	B F R S
M030	White-tailed Jackrabbit	Shrubs/grass-forbs	360	B F R S

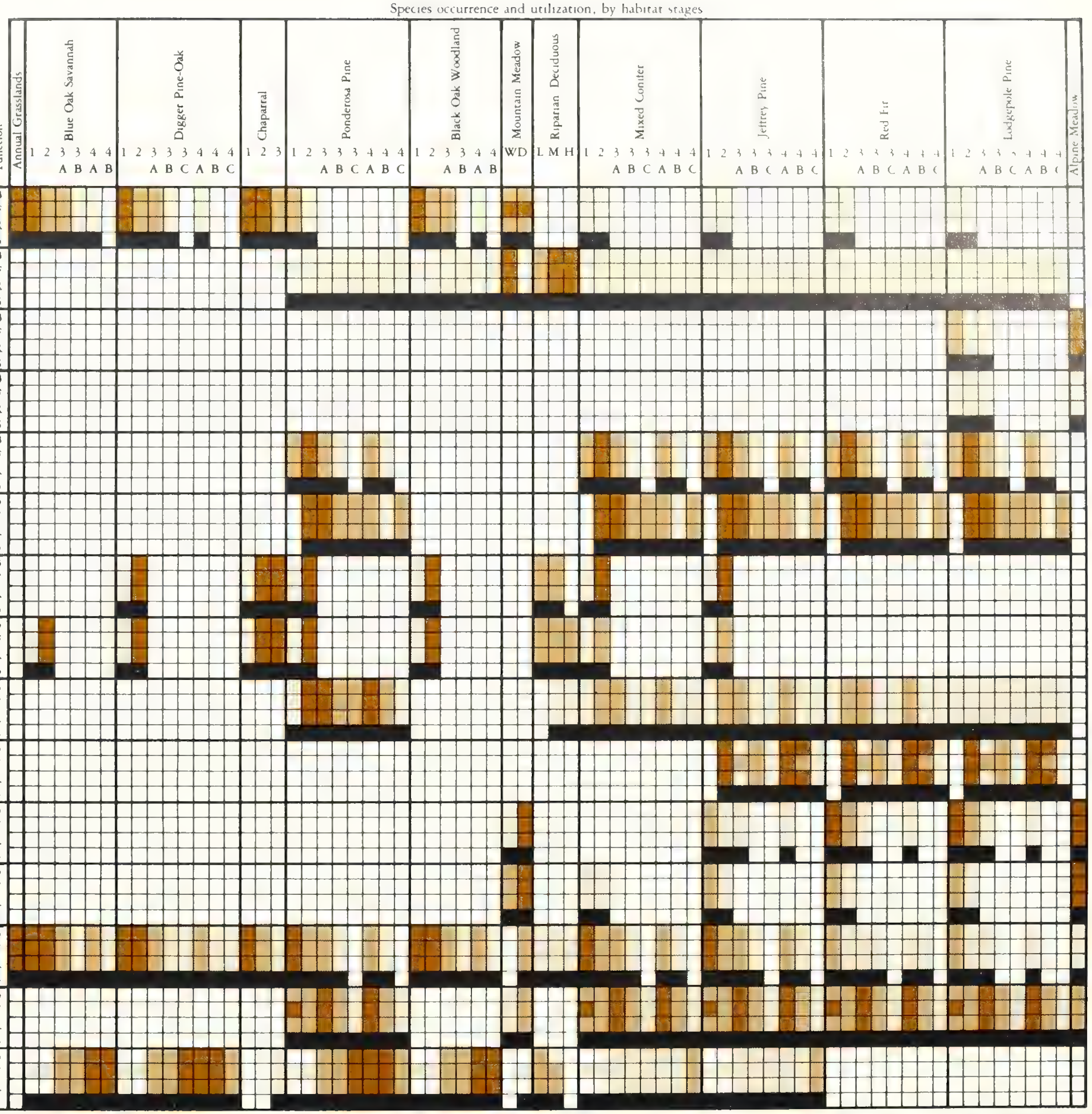


LEGEND

For key to this matrix see *figure 2*

Code	Species	Special Habitat Requirements	Page	Function
[illegible]	Black-tailed Jackrabbit	Medium or large forest openings	361	B F R S
M032	Mountain Beaver	Trees/grass-forbs, moist soil	362	B F R S
M033	Alpine Chipmunk	Talus, logs	363	B F R S
M034	Least Chipmunk	Large forest openings, stumps, logs, or rocks, shrubs	364	B F R S
M035	Yellow Pine Chipmunk	Trees/shrubs	365	B F R S
M036	Allen's Chipmunk	Trees/shrubs, logs, stumps, snags, rocks, or litter	366	B F R S
M037	Sonoma Chipmunk	Trees/shrubs; logs, stumps, snags, rocks, or litter	367	B F R S
M038	Merriam's Chipmunk	Trees/shrubs, logs, stumps, snags, rocks, or litter	368	B F R S
M039	Long-eared Chipmunk	Logs, stumps, snags, rocks, or litter	369	B F R S
M040	Lodgepole Chipmunk	Trees/shrubs, snags, logs, stumps, rocks, or litter	370	B F R S
M041	Yellow-bellied Marmot	Talus or rock outcrops; forest openings	371	B F R S
M042	Belding's Ground Squirrel	Forest openings; friable soils	372	B F R S
M043	California Ground Squirrel	Forest openings; friable soils	373	B F R S
M044	Golden-mantled Ground Squirrel	Logs, stumps, or rocks	374	B F R S
M045	Western Gray Squirrel	Nest cavities in snags or trees, oaks	375	B F R S

Species occurrence and utilization, by habitat stages

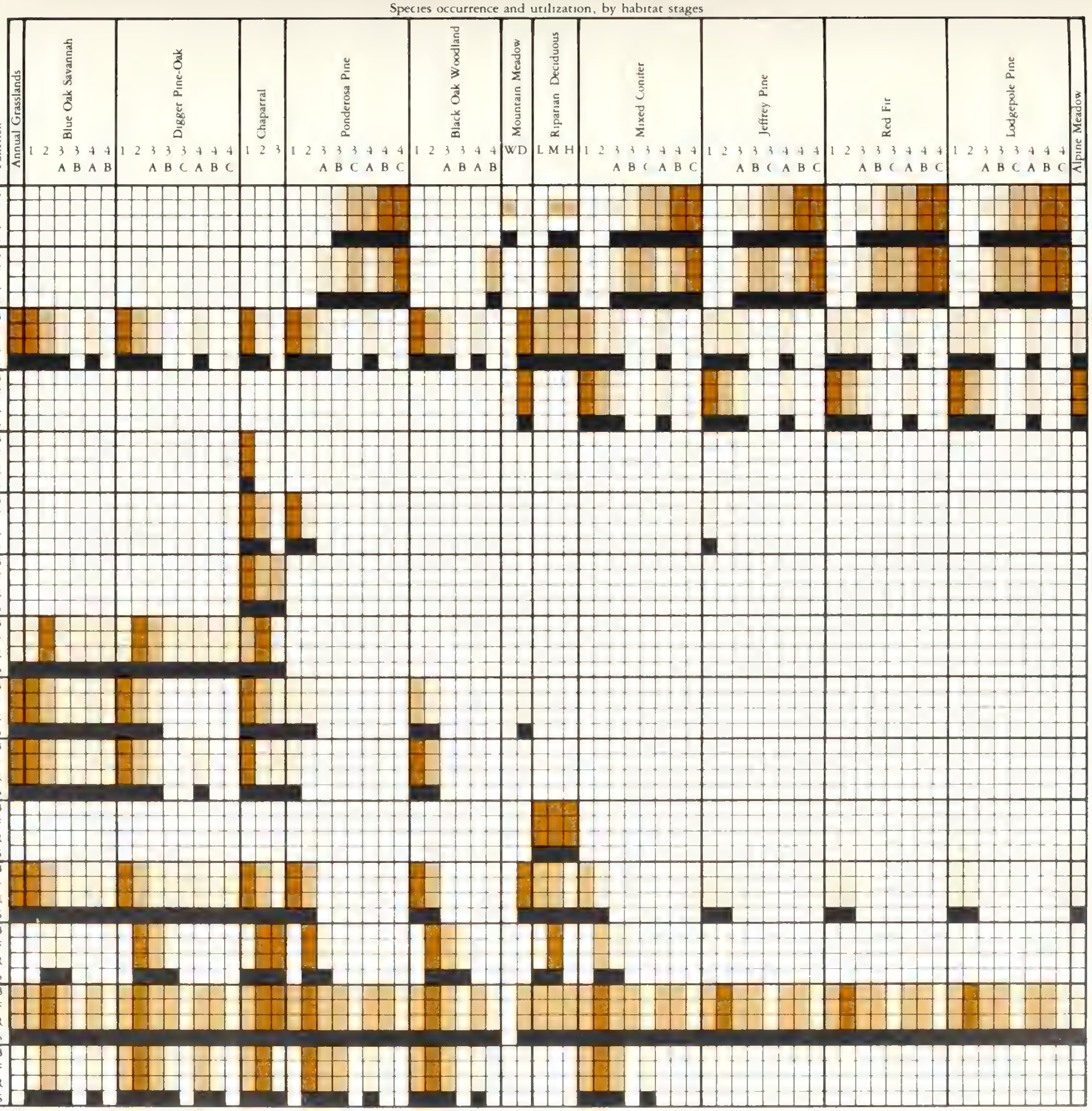


LEGEND

- Optimum Habitat (1)
- Suitable Habitat (2)
- Marginal Habitat (3)
- Spring
- Summer
- Fall
- Winter

For key to this matrix, see *figure 2*

Code	Species	Special Habitat Requirements	Page	Function
M046	Douglas' Squirrel	Trees or snags with nest cavities, conifer seeds	376	B F R S
M047	Northern Flying Squirrel	Trees or snags with nest cavities	377	B F R S
M048	Botta's Pocket Gopher	Friable soils, forest openings	378	B F R S
M049	Mountain Pocket Gopher	Friable soils, forest openings	379	B F R S
M050	Little Pocket Mouse	Medium or large forest openings	380	B F R S
M051	Great Basin Pocket Mouse	Friable soils; large forest openings	381	B F R S
M052	Yellow-eared Pocket Mouse	Friable soils; forest openings	382	B F R S
M053	California Pocket Mouse	Friable soils, shrubs/grass-forbs	383	B F R S
M054	Heermann's Kangaroo Rat	Friable soils; forest openings; sand	384	B F R S
M055	California Kangaroo Rat	Friable soils, forest openings, sand	385	B F R S
M056	Beaver	Permanent streams, ponds, or lakes; aspen, willow, alder or cottonwood thickets	386	B F R S
M057	Western Harvest Mouse		387	B F R S
M058	California Mouse	Trees/shrubs, logs, snags, stumps, or litter	388	B F R S
M059	Deer Mouse		389	B F R S
M060	Brush Mouse	Trees/shrubs, logs, rocks, or litter	390	B F R S



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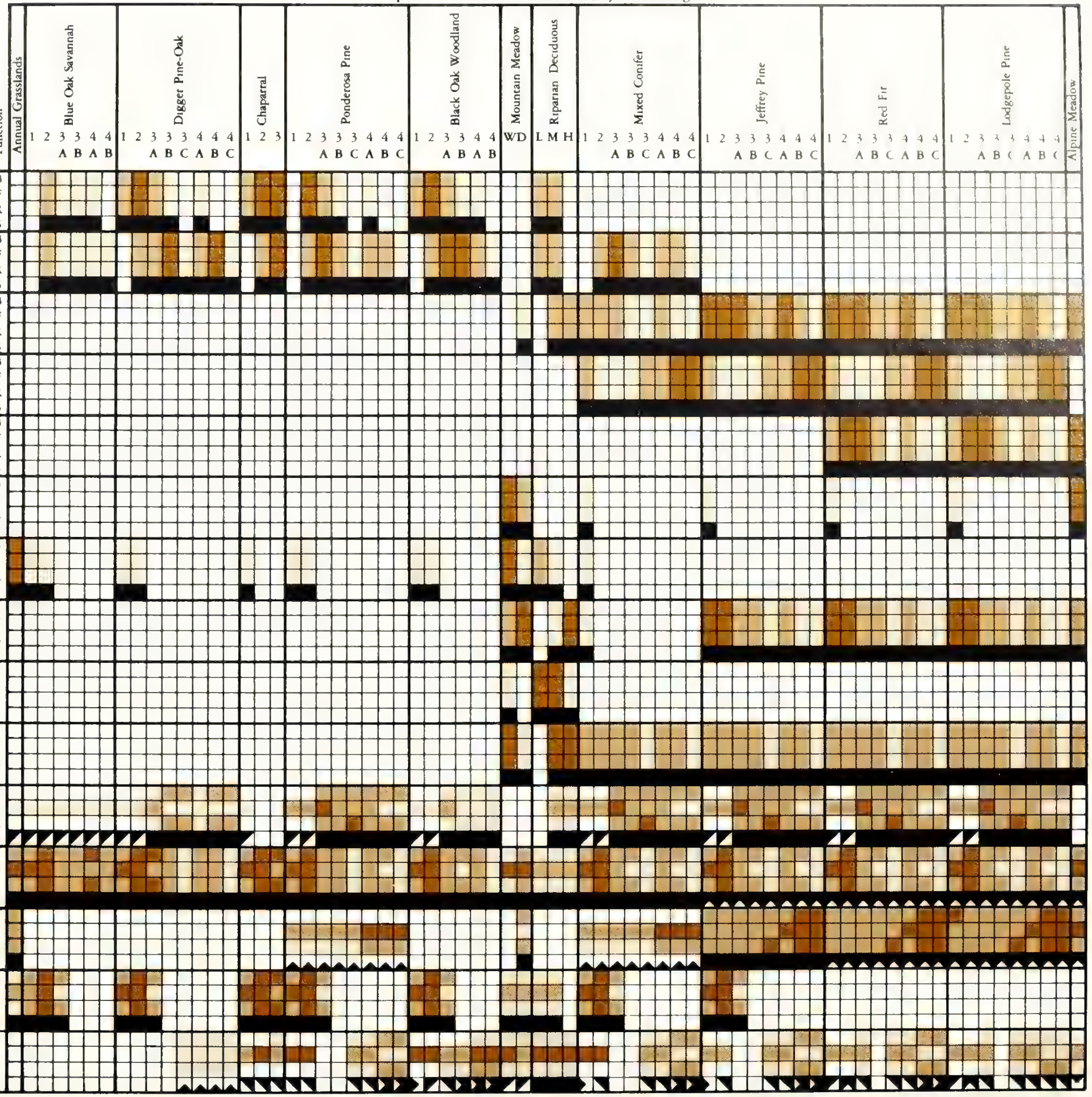
Species occurrence and utilization, by habitat stages

Code	Species	Special Habitat Requirements	Page	Function
M061	Piñon Mouse	Trees/shrubs, small trees, rock outcrops or talus	391	B F R S
M062	Dusky-footed Woodrat	Trees/shrubs; litter	392	B F R S
M063	Bushy-tailed Woodrat	Talus or rock outcrops	393	B F R S
M064	Western Red-backed Vole	Logs, snags, stumps, or litter	394	B F R S
M065	Heather Vole		395	B F R S
M066	Montane Vole	Grasses and/or sedges	396	B F R S
M067	California Vole	Grasses and/or sedges	397	B F R S
M068	Long-tailed Vole	Grasses, sedges, and/or forbs	398	B F R S
M069	Muskrat	Permanent streams, ponds or lakes; grasses and/or sedges	399	B F R S
M070	Western Jumping Mouse	Moist soil	400	B F R S
M071	Porcupine	Trees/shrubs or trees/grass-forbs	401	B F R S
M072	Coyote	Caves, hollows, talus, rock outcrops, or friable soils	402	B F R S
M073	Red Fox	Caves, hollows, talus, rock outcrops, or friable soil; forest openings	403	B F R S
M074	Gray Fox	Caves, hollows, talus, rock outcrops, or friable soils	404	B F R S
M075	Black Bear	Caves, talus, hollows	405	B F R S



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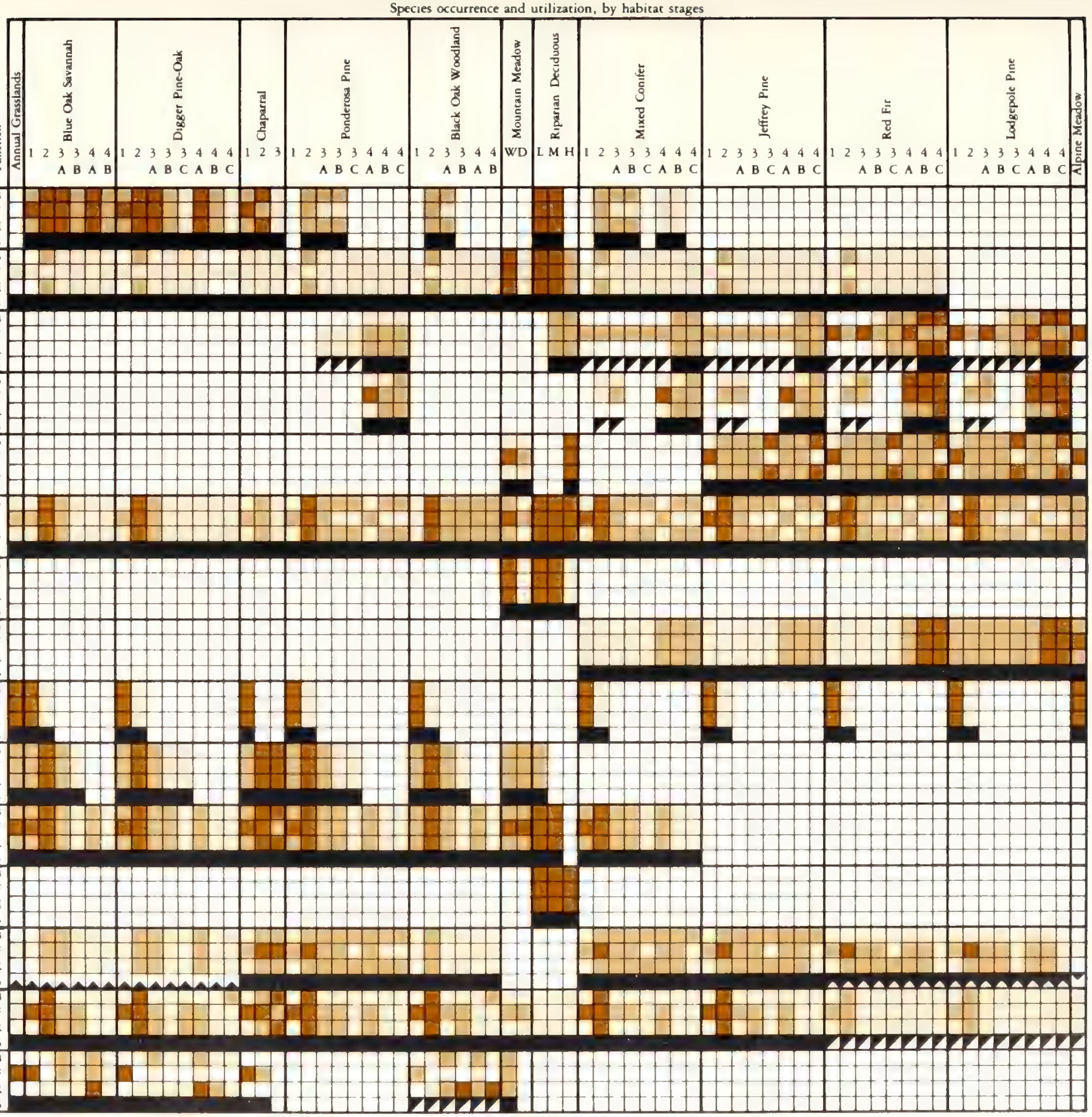
For key to this matrix, see *figure 2*.

Species occurrence and utilization, by habitat stages

Code	Species	Special Habitat Requirements	Page	Function
M076	Ringtail	Rock outcrops or hollows	406	B F R S
M077	Raccoon	Snags or hollows; water	407	B F R S
M078	Marten	Snags; talus	408	B F R S
M079	Fisher	Snags or hollows	409	B F R S
M080	Ermine	Litter, logs, stumps, or snags; forest openings	410	B F R S
M081	Long-tailed Weasel	Forest openings, logs, stumps, or burrows	411	B F R S
M082	Mink	Permanent streams, ponds or lakes; earthen banks	412	B F R S
M083	Wolverine RARE	Low human disturbance, talus, rock outcrops, caves, logs, or snags	413	B F R S
M084	Badger	Forest openings, friable soils	414	B F R S
M085	Western Spotted Skunk	Logs, talus, rock outcrops, or snags	415	B F R S
M086	Striped Skunk	Logs, talus, rock outcrops, or snags	416	B F R S
M087	River Otter	Permanent streams, rivers, or lakes	417	B F R S
M088	Mountain Lion	Deer for food; den sites in rock outcrops, talus, or caves	418	B F R S
M089	Bobcat	Rock outcrops, talus, caves, or hollow logs	419	B F R S
M090	Wild Horse	Grasses, water	420	B F R S



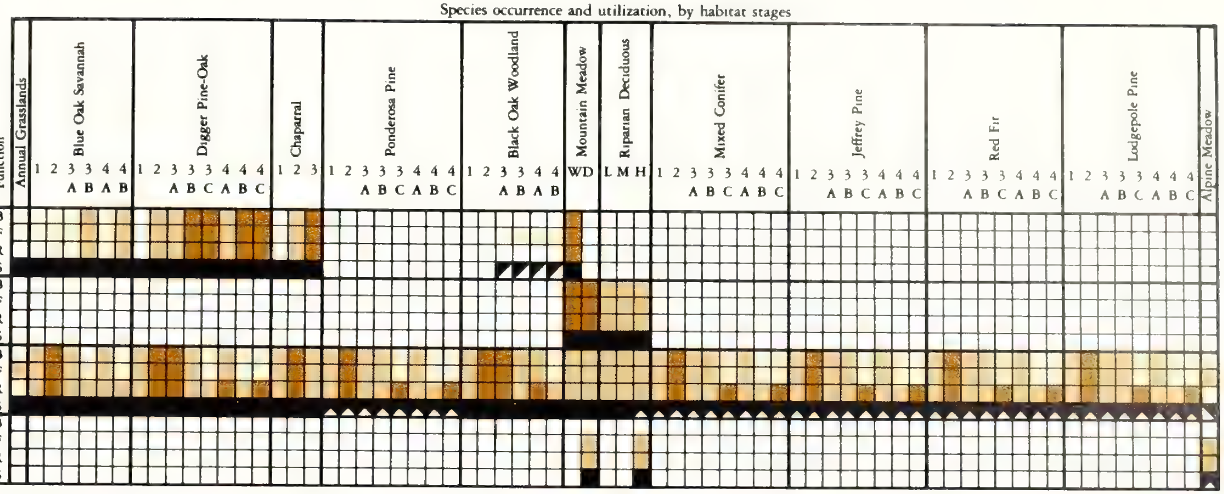
LEGEND

- Optimum Habitat (1)
- Suitable Habitat (2)
- Marginal Habitat (3)
- Spring
- Summer
- Fall
- Winter

For key to this matrix, see *figure 2*.

Code	Species	Special Habitat Requirements	Page	Function
M091	Wild Pig	Water; shrubs	421	B F R S
M092	Wapiti	Trees/shrubs; forest openings; grasses	422	B F R S
M093	Mule Deer	Trees/shrubs, especially for cover on winter range	423	B F R S
M094	Mountain Sheep **RARE**	Low human disturbance; rock outcrops	424	B F R S

Species occurrence and utilization, by habitat stages



Opossum

M001 *(Didelphis virginiana)*

STATUS: No official listed status. Believed expanding its range northward.

DISTRIBUTION/HABITAT: Widespread in valleys and foothills of California. Frequents moist riparian areas in early successional stages of habitats containing oaks. Usually found around buildings, culverts, rock piles, and in trees and snags.

SPECIAL HABITAT REQUIREMENTS:

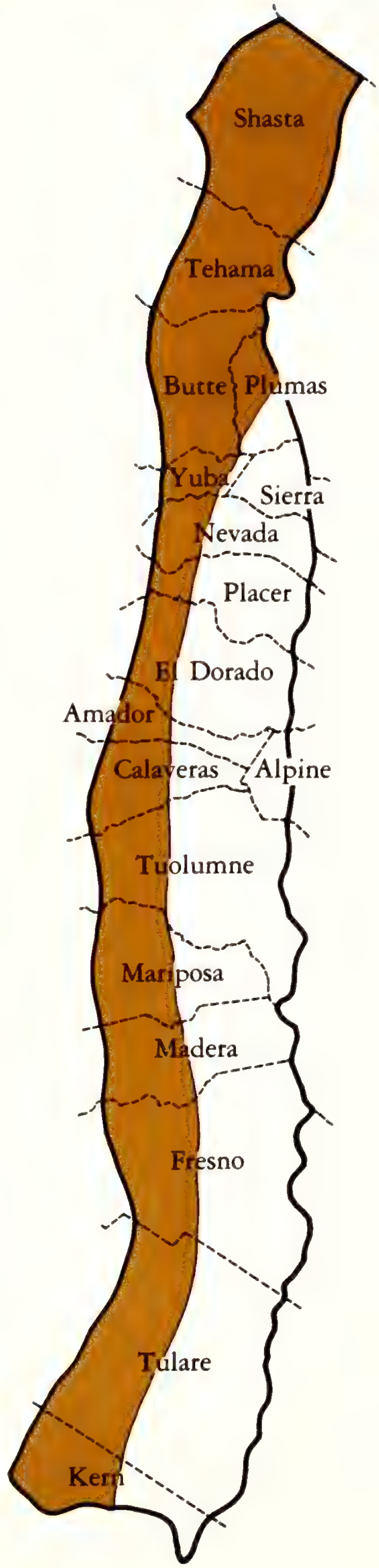
BREEDING: Breeds from January to October, with peaks in February and June; may have two or three litters per year. Nests in trees or snags, rock piles, under buildings, downed logs, or brush piles. Litter size from 5 to 14, (mean of 8). Gestation period 14 days; young carried in pouch 2 months, later ride on mother's back.

TERRITORY/HOME RANGE: Little information on territory, but believed not to be territorial. Home ranges vary from less than 2.5 to 57 acres (1 to 23 ha) (mean 10 to 12 acres [4 to 5 ha]). Often follows water courses; may range widely in fall.

FOOD HABITS: Eats variety of foods including insects, carrion, small mammals, eggs, fruits, and grains. Feeds primarily at night, gleaning from ground and in bushes and trees. May also feed during day.

OTHER: Introduced into California in 1910; the only marsupial in the United States.

REFERENCES: Lay 1942, Petrides 1949, Ingles 1965, and McManus 1974.



Mount Lyell Shrew

M002 *(Sorex lyelli)*

STATUS: No official listed status. Some sources refer to as rare.

DISTRIBUTION/HABITAT: Limited to areas within or near Yosemite National Park, in vicinity of Mt. Lyell. Favors riparian areas and other wet sites.

SPECIAL HABITAT REQUIREMENTS: Moist soil.

BREEDING: No information; probably breeding similar to that of dusky shrew.

TERRITORY/HOME RANGE: No information, but probably similar to dusky shrew.

FOOD HABITS: No information available, but probably eats insects and other invertebrates. Probably forages on ground and in rotted stumps and logs.

OTHER: Essentially no published information on biology of species. Closely related to the masked shrew *(Sorex cinereus)*.

REFERENCES: Grinnell and Storer 1924, Ingles 1965.

Vagrant Shrew

M003 *(Sorex vagrans)*

STATUS: No official listed status. Most common shrew in mid-elevations of the western Sierra Nevada.

DISTRIBUTION/HABITAT: Found from middle to high elevations of the Sierra Nevada, in and around riparian areas.

SPECIAL HABITAT REQUIREMENTS: Moist soil; rotted logs, stumps, or litter.

BREEDING: Breeds from January to August, with peak from March to May. Litter size from 2 to 9 (mean of 6). Normally one litter per year, sometimes two. Nests in stumps and logs.

TERRITORY/HOME RANGE: Possibly territorial, but no information available. Home range small, varying from 0.007 to 0.2 acre (0.003 to 0.07 ha) (average 0.1 acre [0.04 ha]). Home range sizes vary with age of animal and season, and are probably shaped to follow riparian areas.

FOOD HABITS: Eats insects, spiders, earthworms, other invertebrates, and some plant material. Forages through ground litter, under vegetation, and beneath logs, stumps, and rocks. Consumes food equal to own weight each day.

OTHER: Solitary and secretive; active all year, and intermittently day and night.

REFERENCES: Clothier 1955; Ingles 1961, 1965; Hawes 1977; Terry 1978.

Dusky Shrew

M004 *(Sorex monticolus)*

STATUS: No official listed status. Common at high elevations in the western Sierra Nevada.

DISTRIBUTION/HABITAT: Closely associated with riparian habitats in Jeffrey pine, red fir, and lodgepole pine habitats. Rarely found more than a few meters from water in summer.

SPECIAL HABITAT REQUIREMENTS: Moist soil; stumps, logs, or litter.

BREEDING: Breeds from February through October, with peak in late spring or early summer. Litter size from 4 to 7 (mean of 5). Usually two or more litters per year. Nests in logs, stumps, litter, or in holes in ground.

TERRITORY/HOME RANGE: No data on territory available. Home range varies with age of animal and season from 0.007 to 0.2 acre (0.003 to 0.07 ha) (mean of 0.1 acre [0.04 ha]).

FOOD HABITS: Eats insects, spiders, other invertebrates, and some plant matter. Feeds by searching wet areas, logs and stumps, and plant cover.

OTHER: Solitary and secretive, active throughout the year, and intermittently day and night.

REFERENCES: Ingles 1960, 1965; Hawes 1977.

Ornate Shrew

M005 *(Sorex ornatus)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Found at lower elevations, with optimum habitats in riparian areas and brushy hillsides of the digger pine-oak, chaparral, and yellow pine communities. Fairly widespread in the central Sierra Nevada, and found in a small area north of Kern Gap.

SPECIAL HABITAT REQUIREMENTS: Moist soil; stumps, logs, or litter.

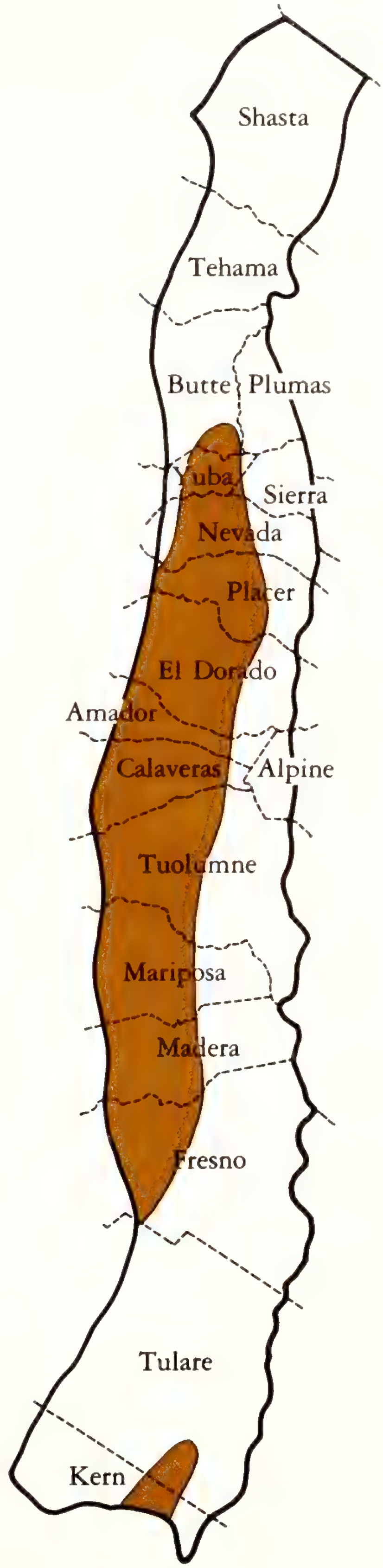
BREEDING: Breeds from spring to summer, but little information available. Nests in dead wood, brush, and burrows.

TERRITORY/HOME RANGE: Litter size thought to average about 6. More than one litter per year expected, but no data available.

FOOD HABITS: Feeds on insects and other invertebrates; searches in riparian areas under logs and rocks and in leaf litter.

OTHER: A solitary, secretive animal, active all year, and intermittently day and night.

REFERENCES: Ingles 1965.



Water Shrew

M006 (*Sorex palustris*)

STATUS: No official listed status. Common within its restricted habitat; adversely affected by stream silting and increased turbidity.

DISTRIBUTION/HABITAT: Found in riparian areas at middle and high elevations in the Sierra Nevada. Requires small, cold streams and wet areas with protected stream banks and ground cover.

SPECIAL HABITAT REQUIREMENTS: Clear, cold streams.

BREEDING: Breeds from January to July, with peak in April to June. May have more than one litter per year. Litter size from 5 to 8 (mean of 6). Nests in secluded, protected banks often constructed of moss and near water.

TERRITORY/HOME RANGE: Little information available, but not territorial in captivity. Home range small and closely associated with a stream or wet area.

FOOD HABITS: Forages along streambanks, water edges, and in water. Foods include insects, tadpoles, fish eggs, invertebrates, and fish.

OTHER: Active all year, intermittently day and night.

REFERENCES: Conaway 1952, Sorenson 1962, Ingles 1965.

Trowbridge's Shrew

M007 *(Sorex trowbridgii)*

STATUS: No official listed status. Common and widespread.

DISTRIBUTION/HABITAT: Found throughout the length of the Sierra Nevada in mid-elevation habitats in both dry and wet areas. Optimum habitats in the more mature tree stages of ponderosa pine and mixed-conifer forests.

SPECIAL HABITAT REQUIREMENTS: Stumps, logs, or litter required as nesting and foraging sites.

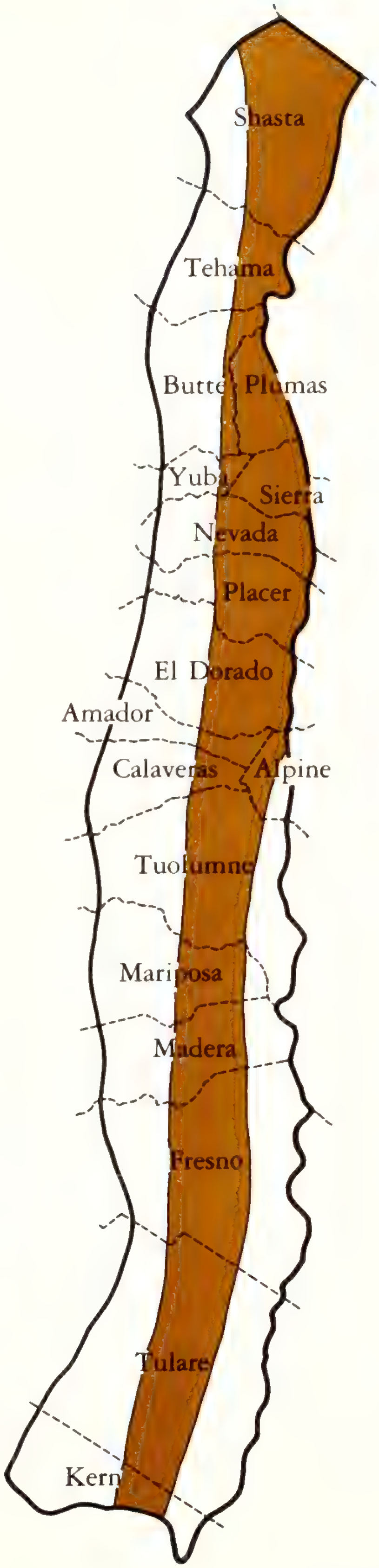
BREEDING: Breeds from February to June, with peak from March to May. Litter size from 1 to 6 (mean of 5). More than one litter per year. Nests in or under logs, or in shallow holes in the ground.

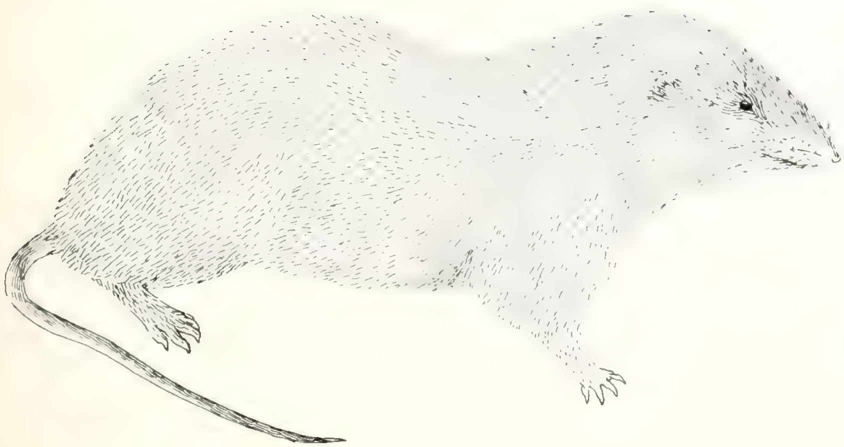
TERRITORY/HOME RANGE: No information available on territory or home range.

FOOD HABITS: Eats much plant material, especially seeds, as well as insects and other invertebrates. Searches for food on ground, primarily near wet areas; forages in upland sites with tree cover.

OTHER: Like other shrews, secretive and solitary. Individuals active intermittently day and night throughout year.

REFERENCES: Jameson 1955, Tevis 1956, Ingles 1965.





Shrew-mole

M008 *(Neurotrichus gibbsii)*

STATUS: No official listed status. A rare species of local distribution in northern part of the western Sierra Nevada.

DISTRIBUTION/HABITAT: Recorded from a single locality within the western Sierra Nevada (Hall and Kelson 1959). Also known from Mt. Shasta area. Found in damp to wet, shaded ravines with silty soil of high humus content and accumulation of litter on surface. Also found in litter on forest floor and along margins of protected marshes, swamps, and bogs.

SPECIAL HABITAT REQUIREMENTS: Friable soils of high humus content; damp, protected sites with cover of surface litter, rotting logs or stumps, or ravines with deciduous growth.

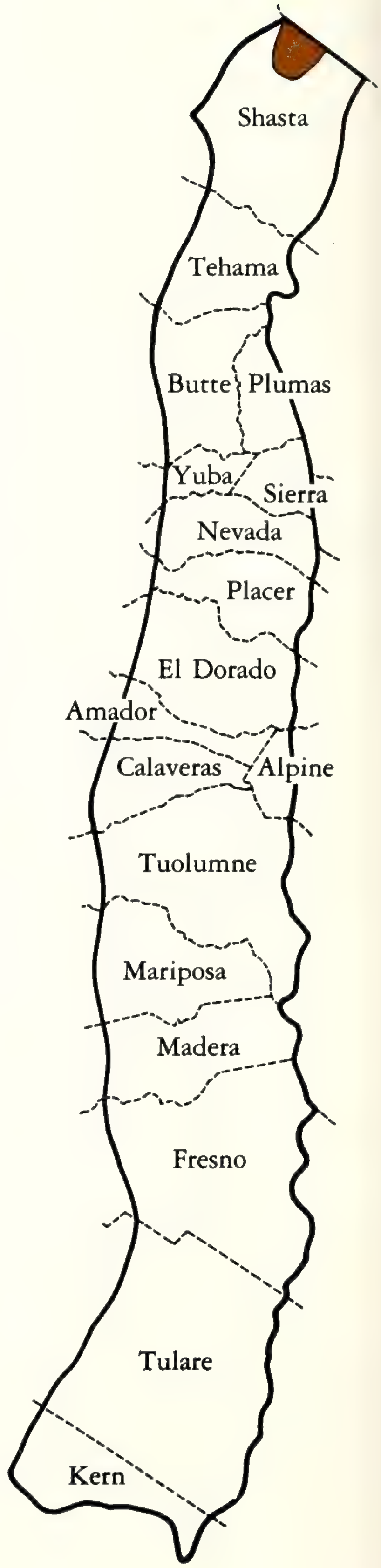
BREEDING: In western Washington, breeds from at least February to September, with peak between March and May. Number of litters not known. Litter size ranges from 1 to 4 (mean of 3). Gestation period and other aspects of reproduction unknown.

TERRITORY/HOME RANGE: Apparently not territorial; the size of home ranges unknown. Gregarious and apparently travel in loose bands of up to 11 or more individuals (Dalquest and Orcutt 1942). Under normal conditions in good habitat, population density averages about 5 or 6 individuals per acre (0.4 ha).

FOOD HABITS: Eats variety of small animals, including earthworms, isopods, various insects, slugs, spiders, and centipedes. Searches for food on ground, within decaying logs, and beneath and within surface litter. Captive individuals ate variety of seeds, including those of conifers and several herbs and shrubs, and several types of fungi. Captive individuals consumed up to 14 g of earthworms in 12 hours (average body weight about 10 g) (Terry 1978).

OTHER: Probably more widespread in the northern Sierra Nevada than indicated by extant records.

REFERENCES: Dalquest and Orcutt 1942, Williams 1975, Terry 1978.



Broad-footed Mole

M009 *(Scapanus latimanus)*

STATUS: No official listed status. Common in suitable habitats.

DISTRIBUTION/HABITAT: Widespread at all elevations throughout the Sierra Nevada. Favors moist areas, especially near streams, bogs, and meadows.

SPECIAL HABITAT REQUIREMENTS: Moist areas with friable soils for burrowing; forest openings.

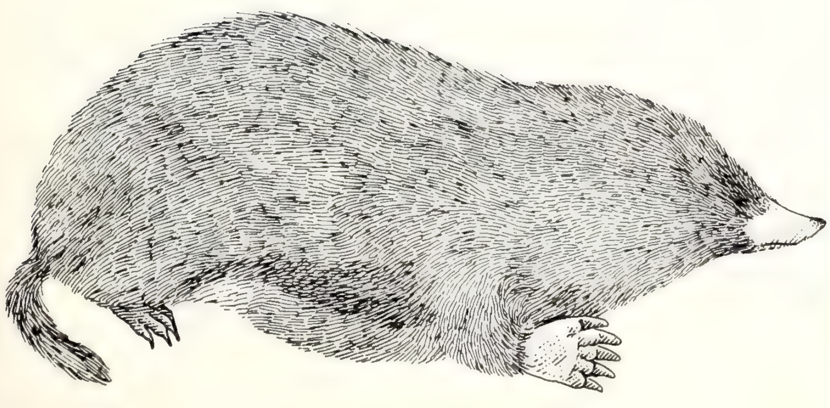
BREEDING: Breeds from March to May. Litter size from 2 to 5; one litter per year. Nests in portion of deep tunnel lined with grass and leaves.

TERRITORY/HOME RANGE: Highly territorial; home range and territory the same, size varying with food supply.

FOOD HABITS: Eats earthworms, insects (adults, larvae, and pupae) spiders, centipedes, and some plant matter. Tunnels beneath surface for food. Constantly patrols and expands these shallow tunnel systems.

OTHER: Provides a beneficial service by mixing and aerating the soil. Constructs two types of burrows: shallow burrows (which show as ridges on the surface) for feeding, and deeper tunnels. Solitary animal; active intermittently day and night throughout year.

REFERENCES: Scheffer 1923, Ingles 1965, Giger 1973.



Little Brown Myotis

M010 (*Myotis lucifugus*)

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Widely distributed and common from middle to high elevations; closely associated with water.

SPECIAL HABITAT REQUIREMENTS: Snags for roosting; caves for hibernation; permanent pools, ponds, or lakes for feeding and drinking.

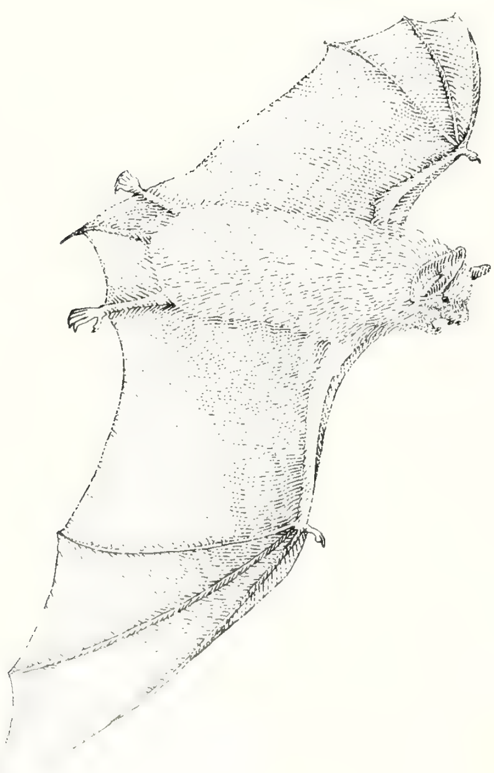
BREEDING: Young born from June to August, with peak in July. Litters of 1 or 2 (mean of 1); one litter per year. Buildings, snags, or other warm, dark retreats used as maternity colony sites. Maternity colonies of up to several hundred individuals usually located close to streams or lakes.

TERRITORY/HOME RANGE: Unknown.

FOOD HABITS: Captures flying insects on the wing. Food detected by echolocation; much foraging over water.

OTHER: Hibernates in winter; primarily a forest dwelling, mountain species.

REFERENCES: Grinnell 1918, Davis and Hitchcock 1956, Humphrey 1969, O'Farrell and Studier 1973.



Yuma Myotis

M011 *(Myotis yumanensis)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Widespread and locally common; closely associated with water. Most common in riparian habitats, from annual grasslands through ponderosa pine forests.

SPECIAL HABITAT REQUIREMENTS: Caves, crevices, snags, buildings, and mines used for resting and breeding colonies. Permanent water (ponds, lakes, pools) required as foraging sites.

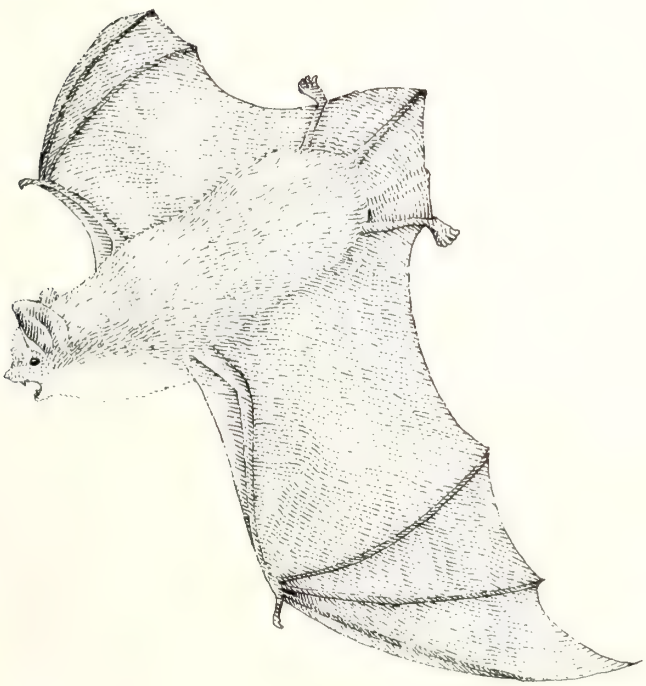
BREEDING: Young born in May and June, with peak in June. One litter per year; mean litter size 1. Buildings, bridges, caves, mines, or crevices used as maternity sites with colonies occasionally up to 1,000 individuals.

TERRITORY/HOME RANGE: Unknown.

FOOD HABITS: Insects taken in flight are major food. Most foraging over water; prey found through echolocation.

OTHER: Migrates from higher elevations in fall; forages low over water.

REFERENCES: Grinnell 1918, Sumner and Dixon 1953, Ingles 1965, Barbour and Davis 1969.



Long-eared Myotis

M012 *(Myotis evotis)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Uncommon; ranges throughout much of western slope of the Sierra Nevada.

SPECIAL HABITAT REQUIREMENTS: Caves, snags, and trees used for roosting and breeding colonies; water.

BREEDING: Young born from May to July, with peak in June. One litter per year; mean litter size 1. Maternity colonies of 12 to 30 females located in buildings, crevices in rocks, behind tree bark, or in snags.

TERRITORY/HOME RANGE: Unknown.

FOOD HABITS: Beetles, moths, and other insects taken in flight; prey located by echolocation; probably a foliage gleaner.

OTHER:

REFERENCES: Orr 1949, Sumner and Dixon 1953, Barbour and Davis 1969, Black 1974, Husar 1976.

Fringed Myotis

M013 *(Myotis thysanodes)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Irregularly distributed in the Sierra Nevada, with most known localities in digger pine-oak through black oak woodland habitats. Winter range unknown.

SPECIAL HABITAT REQUIREMENTS: Caves or rock crevices for roosting and breeding colonies; water.

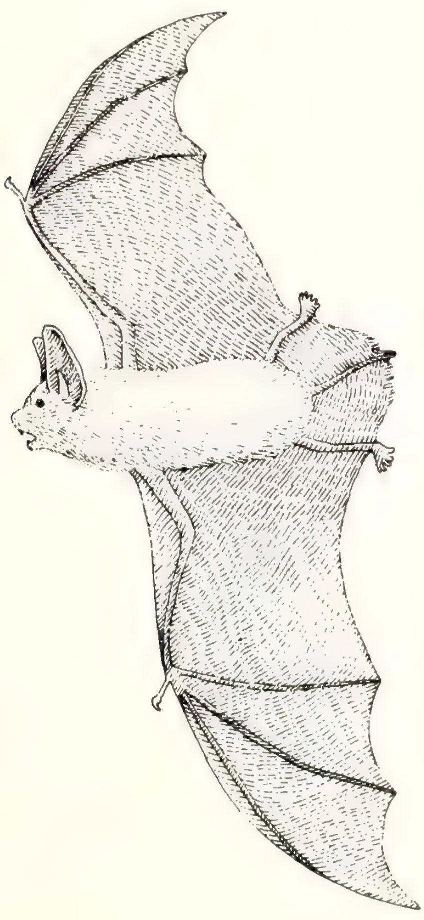
BREEDING: Young born from May to July, with peak in June. One litter per year (mean of 1). Maternity colonies of up to 200 individuals roost in caves, mines, rock crevices, or buildings.

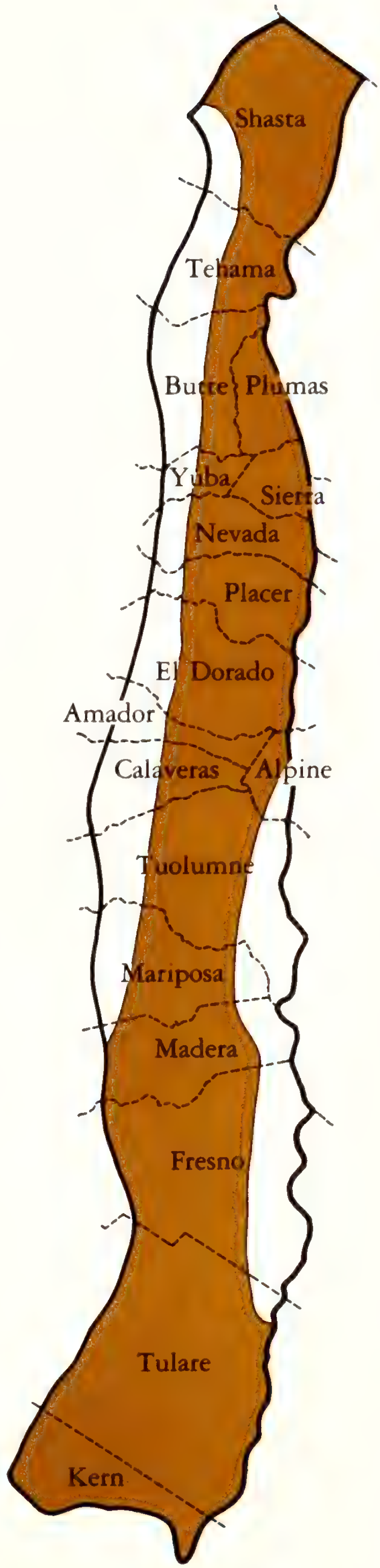
TERRITORY/HOME RANGE: Unknown.

FOOD HABITS: Beetles taken in flight are major food; prey found through echolocation; probably a foliage gleaner.

OTHER:

REFERENCES: Cockrum and Ordway 1959, Barbour and Davis 1969, O'Farrell and Studier 1973, Black 1974.





Long-legged Myotis

M014 (*Myotis volans*)

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Widespread and common as summer resident. Optimum to good habitat in open and moderately open stands of black oak woodland, riparian, and mixed-conifer habitats.

SPECIAL HABITAT REQUIREMENTS: Trees, snags, or crevices for roosting and breeding; water for feeding and drinking.

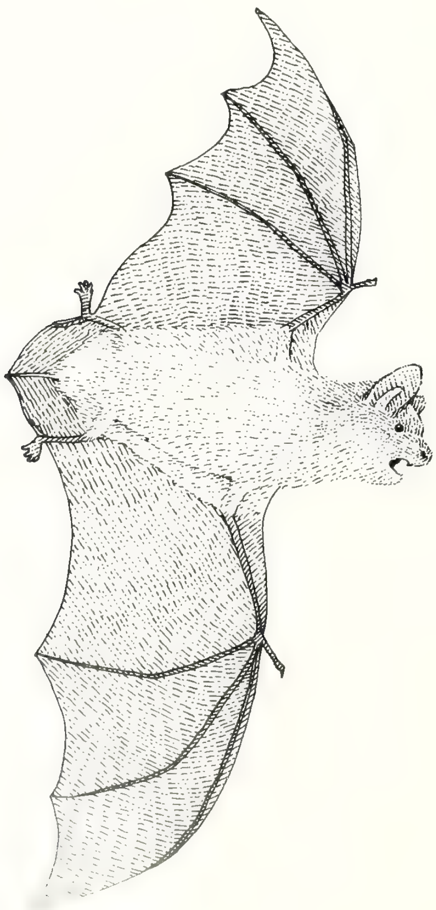
BREEDING: Young born during June and July. One litter per year (mean of 1). Maternity colonies of 100 individuals or more roost in tree crevices, snags, buildings, or rock crevices.

TERRITORY/HOME RANGE: Unknown.

FOOD HABITS: Eats insects, especially moths, captured in the air, over water and woodland openings. Prey found by echolocation.

OTHER: Probably migratory for short distances.

REFERENCES: Sumner and Dixon 1953, Ingles 1965, Barbour and Davis 1969, Black 1974.



California Myotis

M015 *(Myotis californicus)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Widespread throughout the western Sierra Nevada; usually found at elevations below 5000 ft (1500 m).

SPECIAL HABITAT REQUIREMENTS: Crevices in trees, snags, or rocks for roosting and breeding; water.

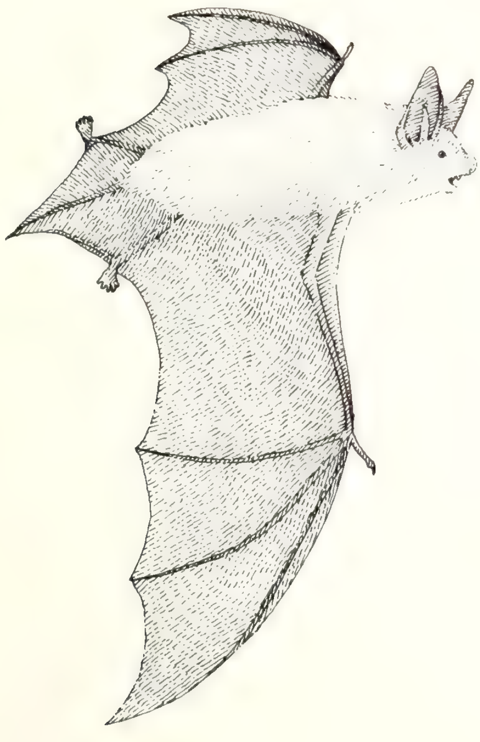
BREEDING: Young born in May and June; one litter per year (mean litter size 1). Roosts in buildings, bridges, holes in snags and trees, behind bark, and rock crevices.

TERRITORY/HOME RANGE: Unknown.

FOOD HABITS: Most food taken from air near ground; mainly flying insects, especially beetles and moths. Prey found by echolocation.

OTHER: Hibernates in winter; may be active on warm winter days at low elevations. Found singly or in small colonies; sexes found separately during warmer months. Flight slow and erratic, close to ground surface. Roosts during day in a variety of crevice-like places.

REFERENCES: Grinnell and Storer 1924, Krutzsch 1954a, Barbour and Davis 1969, Black 1974.



Small-footed Myotis

M016 *(Myotis leibii)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Widespread and locally common; generally most common in relatively arid upland habitats.

SPECIAL HABITAT REQUIREMENTS: Caves, mines, or rock crevices for roosting and breeding; water.

BREEDING: Young born from May to July, with peak in June. One litter per year; mean litter size 1. Buildings, caves, rock crevices, and mines used as maternity sites. Roosts in colonies or singly; maternity colonies of 12 to 20 adult females recorded.

TERRITORY/HOME RANGE: Unknown.

FOOD HABITS: Takes moths, beetles, flies, ants, and other insects in flight; prey found by echolocation.

OTHER: Hibernates in winter.

REFERENCES: Cockrum 1952, Ingles 1965, Barbour and Davis 1969, Black 1974.

Silver-haired Bat

M017 *(Lasionycteris noctivagans)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Widespread along western slope of the Sierra Nevada. Optimum feeding habitat found in forested areas.

SPECIAL HABITAT REQUIREMENTS: Trees and snags for roosting and breeding; water for drinking.

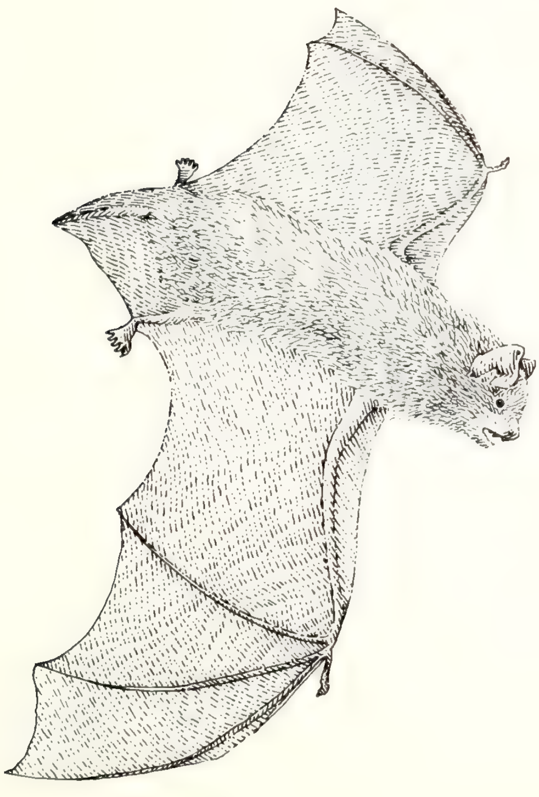
BREEDING: Young born in June and July. Litter size 1 or 2 (mean litter size 2); one litter per year. Usually roosts in solitude in snags, protected crevices in trees, and under bark. Females occasionally form small nursery colonies.

TERRITORY/HOME RANGE: Unknown.

FOOD HABITS: Finds insects, principally moths, through echolocation; prey captured in flight.

OTHER: A slow flier; usually flies close to the ground.

REFERENCES: Orr 1949, Barbour and Davis 1969.



Western Pipistrelle

M018 (*Pipistrellus hesperus*)

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Common, but irregularly distributed below ponderosa pine forests from Kern county north to southern Tehama County.

SPECIAL HABITAT REQUIREMENTS: Rock crevices for roosting and breeding; water.

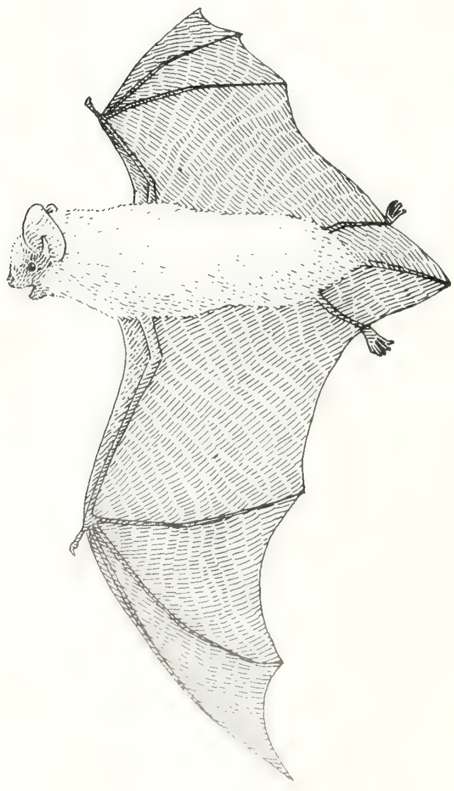
BREEDING: Young born in June and July. Litter size 1 or 2 (mean litter size 2); one litter per year. Roosts colonially in rock crevices. Maternity colonies of up to 12 individuals.

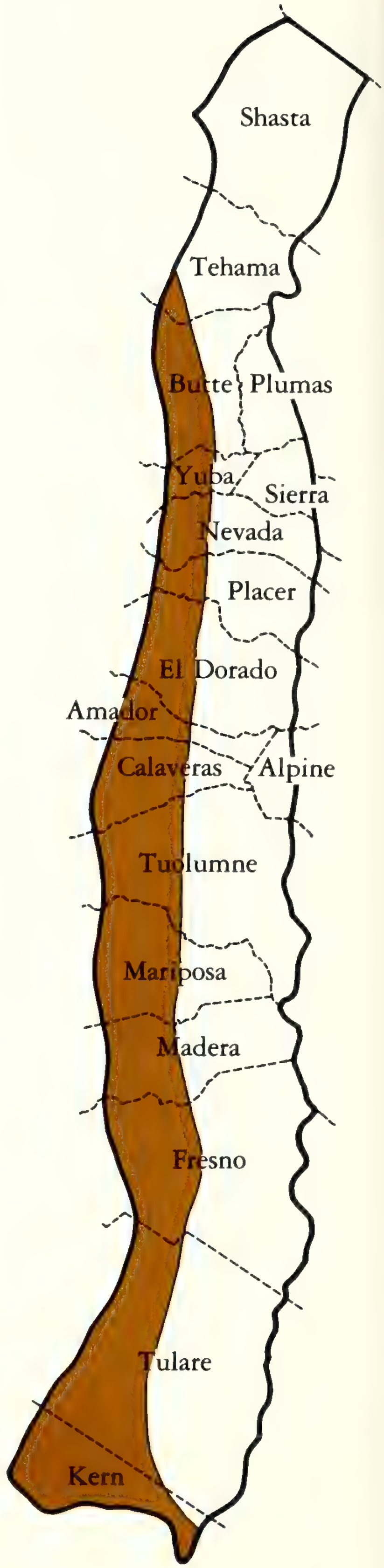
TERRITORY/HOME RANGE: Unknown.

FOOD HABITS: Insects, primarily moths, taken in flight; prey found by echolocation.

OTHER: Primarily found in arid habitats, but not far from water. Activity pattern crepuscular; flight begins early in evening. Active during warm spells in winter.

REFERENCES: Grinnell and Storer 1924, Sumner and Dixon 1953, Barbour and Davis 1969, Black 1974.





Big Brown Bat

M019 *(Eptesicus fuscus)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Widespread throughout western slope of the Sierra Nevada; forest openings and meadows (except alpine) optimum feeding habitats.

SPECIAL HABITAT REQUIREMENTS: Snags, trees, caves, crevices, or buildings for roosting and breeding colonies; water.

BREEDING: Young born from May to July, with peak in June. Litter size 1 or 2 (mean of 1). Buildings, caves, crevices, snags, or trees used for maternity sites.

TERRITORY/HOME RANGE: Unknown, but probably territorial.

FOOD HABITS: Feeds in flight, 13 to 66 ft (4 to 20 m) above the ground. Various insects, mainly beetles, for major food. Prey found by echolocation.

OTHER: Resident species; hibernates in winter. Individuals roost in colonies with other species. Can be found in large maternity colonies in summer and in small colonies (or solitary) in winter. Flies straight and steady.

REFERENCES: Krutzsch 1946, Dalquest 1948, Phillips 1966, Davis *et al.* 1968, Black 1972.

Red Bat

M020 *(Lasiurus borealis)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Found in wooded areas at lower elevations throughout the western Sierra Nevada. Prefers open to moderately dense stands of trees for roosting.

SPECIAL HABITAT REQUIREMENTS: Snags and trees for roosting and breeding; water.

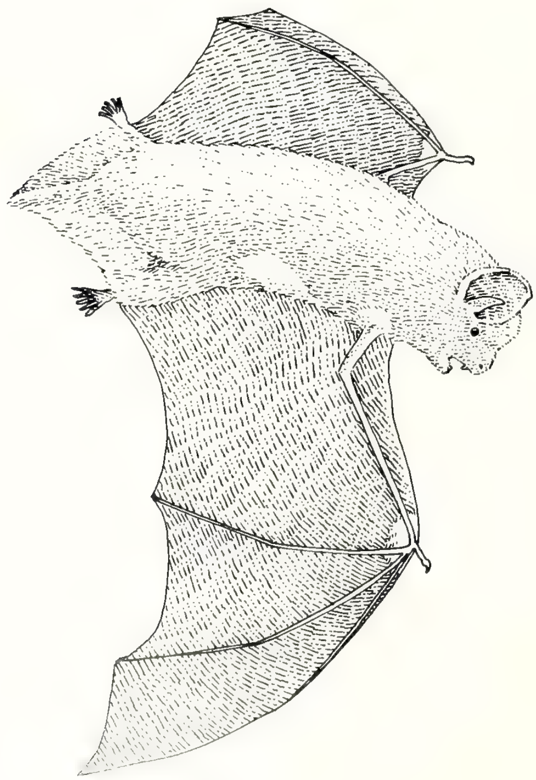
BREEDING: Young born in May and June, with peak in June. One litter per year; mean litter size 3 (range 1 to 4). Nursery sites located in trees.

TERRITORY/HOME RANGE: Unknown. Density of 1/acre (2.5/ha) estimated in study in Midwest (McClure 1942).

FOOD HABITS: Crickets, moths, beetles, cicadas, and other insects taken in flight.

OTHER: Solitary in summer; more colonial in winter. Often roosts in foliage near the ground; winters in western lowlands of California.

REFERENCES: Grinnell 1918, McClure 1942, Hamilton 1943, Jackson 1961, Constantine 1966.



Hoary Bat

M021 *(Lasiurus cinereus)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Widespread throughout western Sierra Nevada region. Breeding habitat in medium and large tree stages of conifer forests. Found throughout the Sierra Nevada during migration.

SPECIAL HABITAT REQUIREMENTS: Trees with dense foliage for roosting and breeding; water.

BREEDING: Litter size averages 2 (range from 1 to 4); one litter per year. Nests in tree foliage with well-developed canopy above, but open below.

TERRITORY/HOME RANGE: Unknown.

FOOD HABITS: Moths are main food, found through echolocation and taken in flight.

OTHER: Roosts singly in foliage of trees; migrates south in winter. Few females in the Sierra Nevada during reproductive season.

REFERENCES: Grinnell and Storer 1924; Provost and Kirpatrick 1952; Black 1972, 1974; Findley *et al.* 1975.

Spotted Bat

M022 *(Enderma maculatum)*

STATUS: Listed in the 1973 edition of *Threatened Wildlife of the United States*, but not officially listed as threatened or endangered.

DISTRIBUTION/HABITAT: Ranges from about Tuolumne to Kern Counties, from annual grasslands up to at least ponderosa pine zone.

SPECIAL HABITAT REQUIREMENTS: Little known, but probably secluded caves, crevices, or snags for roosting and breeding. Large placid pools, ponds, or lakes for drinking.

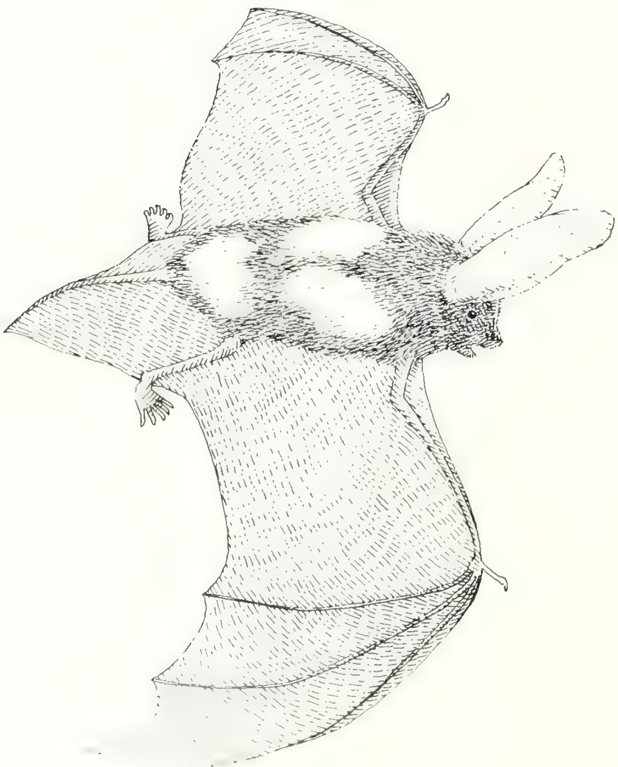
BREEDING: Young born in late spring and summer. Mean litter size 1. Roost site requirements largely unknown, but thought to be crevices in cliffs or secluded caves.

TERRITORY/HOME RANGE: Unknown.

FOOD HABITS: Moths and other insects found through echolocation and taken in flight.

OTHER: May occasionally enter buildings.

REFERENCES: Easterla 1965, Barbour and Davis1969, Easterla and Easterla 1969, Findley *et al.* 1975, Watkins 1977.



Townsend's Big-eared Bat

M023 *(Plecotus townsendii)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Widespread in the western Sierra Nevada.

SPECIAL HABITAT REQUIREMENTS: Caves or crevices for roosting and breeding; water. Especially intolerant of disturbances of maternity colonies and hibernacula by humans.

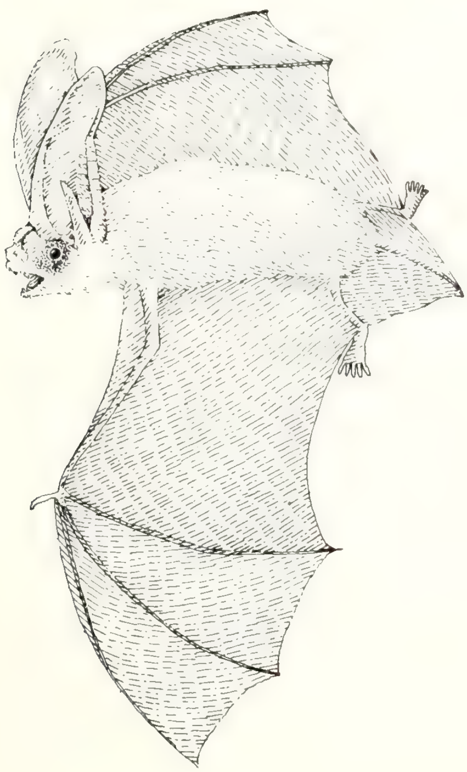
BREEDING: Young born from April to July, with peak in May. Mean litter size 1; one litter per year. Maternity colonies found in caves, mine tunnels, or occasionally in buildings.

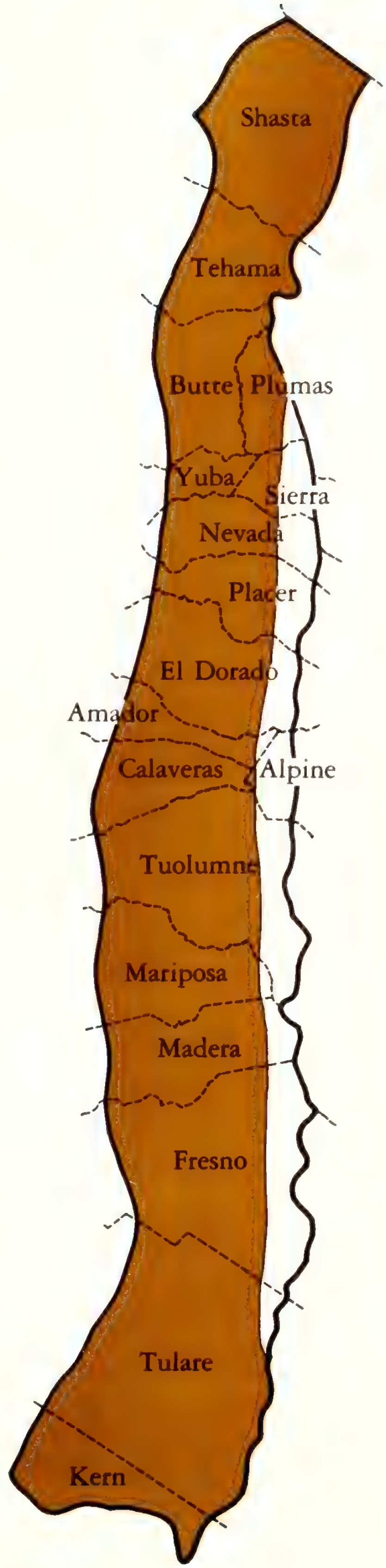
TERRITORY/HOME RANGE: Unknown.

FOOD HABITS: Captures insects, mostly moths, in flight at night by echolocation.

OTHER: Males usually solitary in spring and summer, but hibernate colonially in caves and mines. Residents and can be found throughout range during any season.

REFERENCES: Dalquest 1947, Pearson *et al.* 1952, Barbour and Davis 1969.





Pallid Bat

M024 *(Antrozous pallidus)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Common in arid and semiarid areas at relatively low elevations throughout the western Sierra Nevada. Found from annual grasslands through mixed-conifer forests.

SPECIAL HABITAT REQUIREMENTS: Caves, crevices, or buildings for roosting and breeding colonies; water.

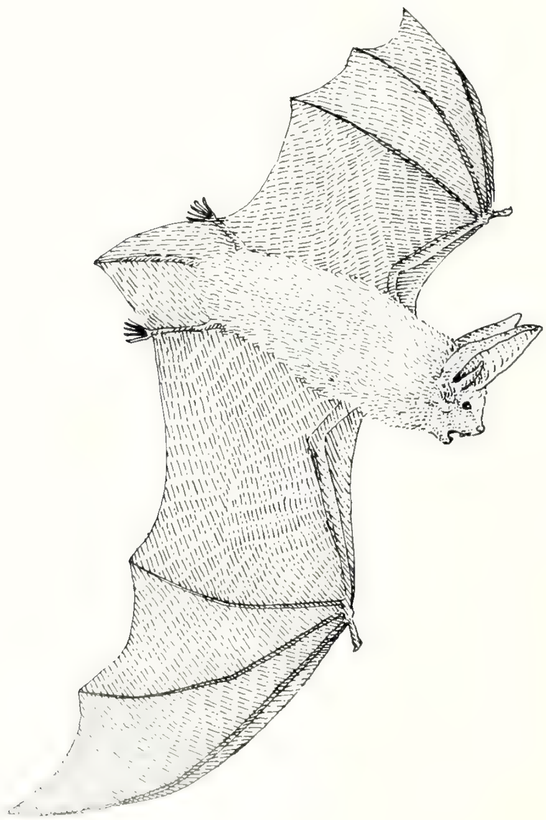
BREEDING: Young born from April to July. Litter size ranges from 1 to 3 (mean of 2); one litter per year. Pregnant females gather in maternity colony to give birth. Rock crevices, caves, buildings, and other areas of semidarkness with protection from above used as roost sites.

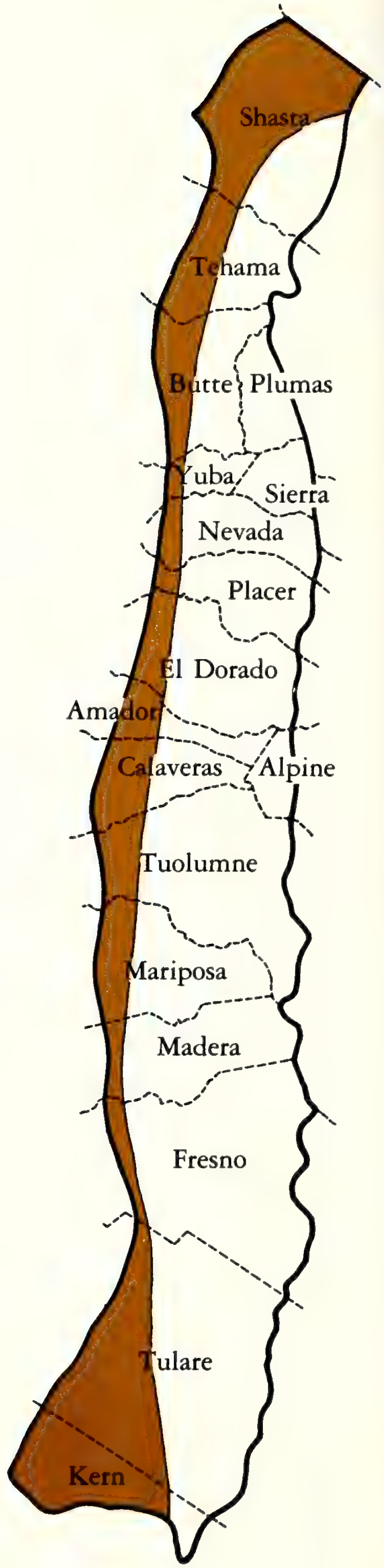
TERRITORY/HOME RANGE: Unknown.

FOOD HABITS: Beetles, moths, orthopterans, and other large insects, as well as scorpions and other invertebrates gleaned from surface of ground and from foliage. Echolocation used to find prey. Perches used when devouring prey.

OTHER: Females roost in colonies of usually less than 100, often associated in colonies with Brazilian free-tailed bats. May hibernate in winter. Separate day and night roosts often used.

REFERENCES: Sumner and Dixon 1953, Orr 1954, Ross 1967, O'Shea and Vaughan 1977.





Brazilian Free-tailed Bat

M025 *(Tadarida brasiliensis)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Widely distributed in California at low elevations. Optimum feeding habitats in annual grassland, chaparral, and meadows.

SPECIAL HABITAT REQUIREMENTS: Crevices, hollow trees, or man-made structures for roosting and breeding; water.

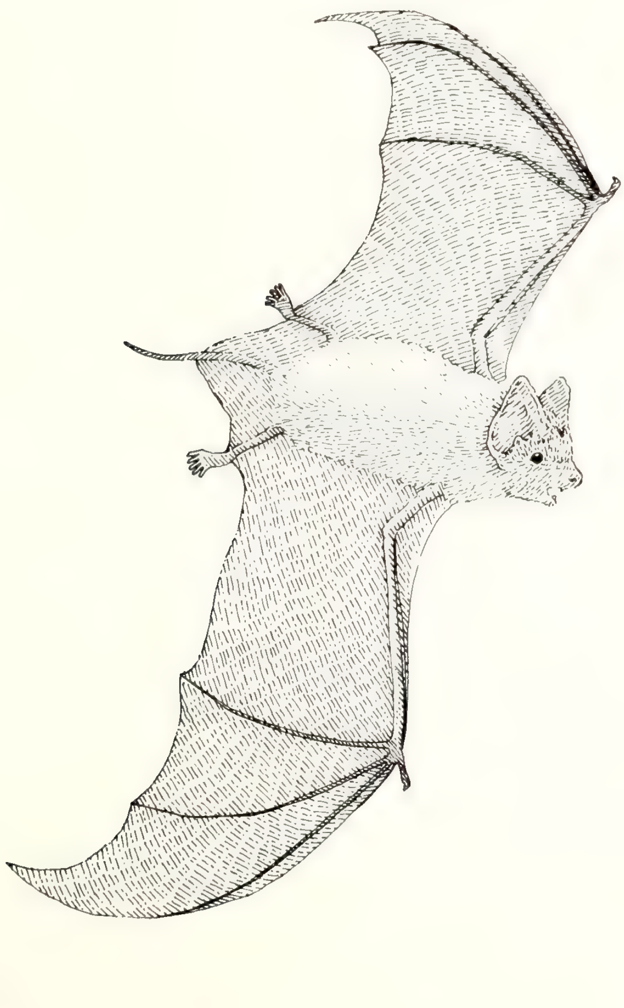
BREEDING: Young born from April to August, with peak in June. Litter size 1 or 2 (mean of 1). Maternity colonies located in cracks and crevices, buildings and other structures, such as bridges.

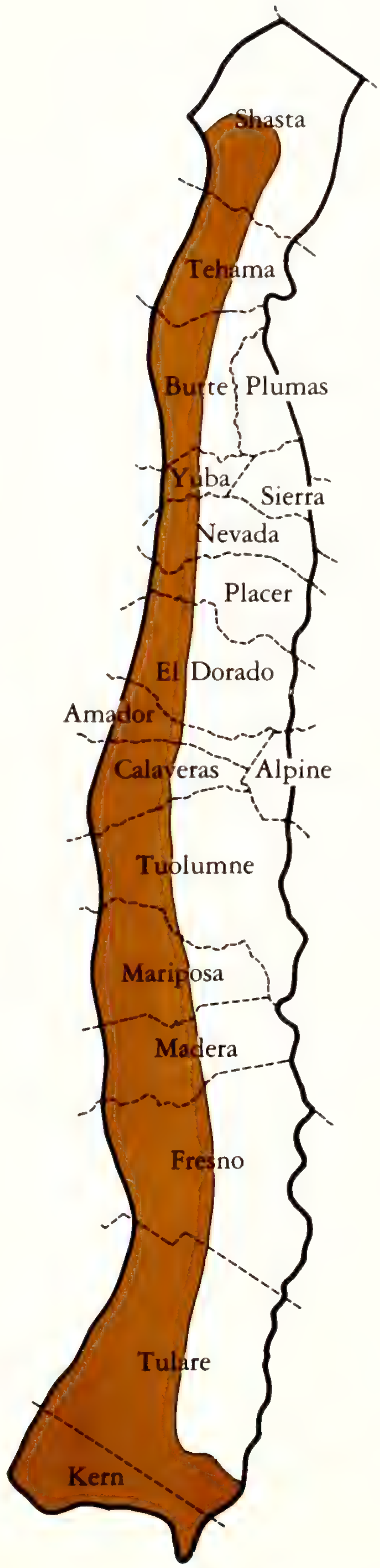
TERRITORY/HOME RANGE: Unknown.

FOOD HABITS: Small moths and other flying insects taken in flight. Prey found through echolocation. May sometimes travel long distances to feed; generally feeds at distances greater than 131 ft (40 m) above ground.

OTHER: Colonial and often found in large maternity colonies. Hibernates in winter.

REFERENCES: Krutzsch 1955, Davis *et al.* 1962, Barbour and Davis 1969.





Pika

M026 *(Ochotona princeps)*

STATUS: No official listed status. Fairly common in preferred habitat.

DISTRIBUTION/HABITAT: Found only in high mountains; confined to talus slopes with adjacent areas (especially alpine meadows) containing herbs and grasses.

SPECIAL HABITAT REQUIREMENTS: Talus slopes and forest openings.

BREEDING: Breeds from May through June or July, occasionally as late as September. Nests in deep crevices between rocks. Litter size from 1 to 5 (mean 2 or 3); one to three litters per year.

TERRITORY/HOME RANGE: Sedentary animal with small home range of 0.74 to 1.24 acre (0.3 to 0.5 ha) and territory of slightly smaller dimensions in Glacier National Park, Montana (Barash 1973).

FOOD HABITS: Eats variety of grasses and forbs, some shrubs. Forages among rocks and in alpine meadows. Dries food and stores it under rocks in small "hay piles" to eat in winter.

OTHER: Active all year, and intermittently day and night.

REFERENCES: Broadbooks 1965, Ingles 1965, Barash 1973.

Brush Rabbit

M027 *(Sylvilagus bachmani)*

STATUS: No official listed status. A game species; may be taken only during rabbit season.

DISTRIBUTION/HABITAT: Distrubuted along western edge of the Sierra Nevada, primarily in Chaparral. Also found in brushy areas of earlier successional stages of oak and pine woodlands.

SPECIAL HABITAT REQUIREMENTS: Large areas of dense cover, such as shrubs, thickets, or vines.

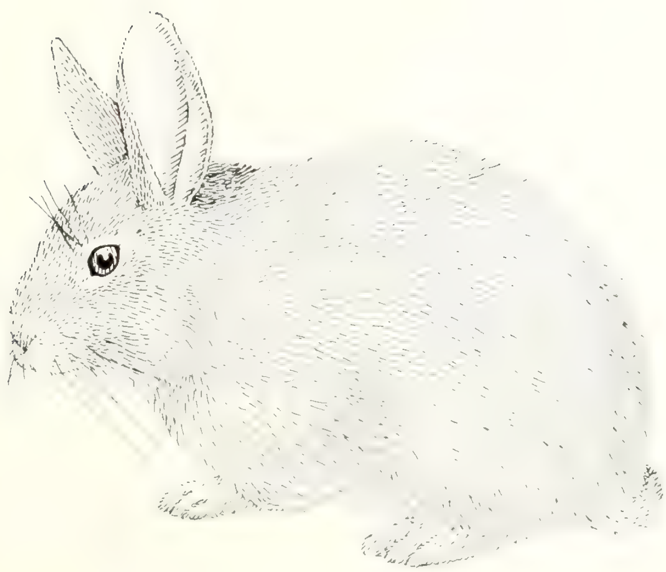
BREEDING: Two to four litters annually, averaging 3 or 4 young each, and ranging up to 6. Breeds from January to August, with peak from March to June. Gestation 28 to 30 days. Nests on ground (in cover) or in a burrow.

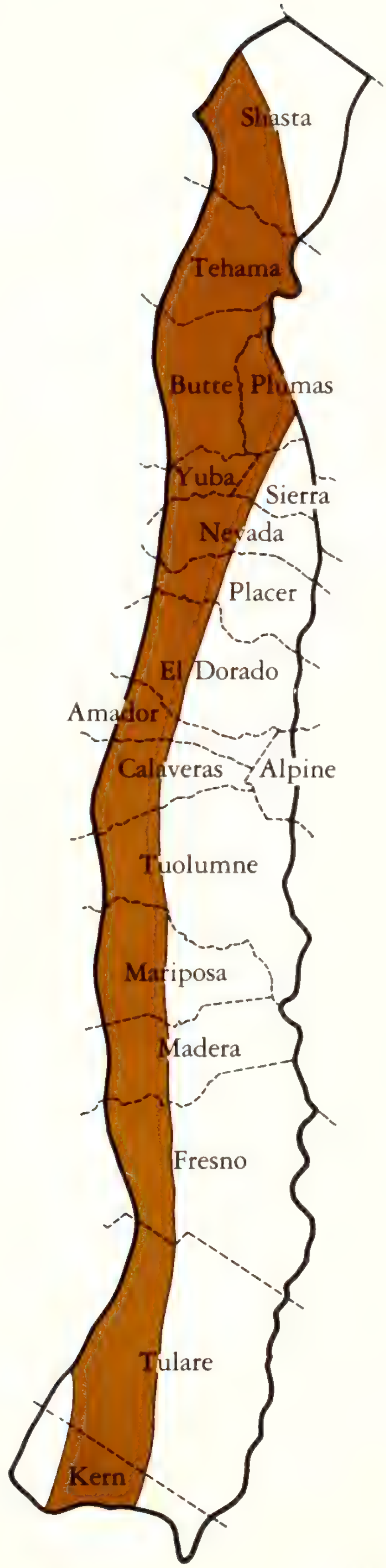
TERRITORY/HOME RANGE: Basically sedentary, with home range sizes of 0.1 to 8 acres (0.04 to 3.2 ha). Near Corvallis, Oregon, home range sizes varied from 0.5 to 2 acres (0.2 to 0.8 ha) (Chapman 1971).

FOOD HABITS: Eats grasses (foxtails, soft chess, oats, and others), forbs, and some browse (*Ceanothus* and others); often feeds in the open, but near brush cover.

OTHER: Crepuscular and active all year.

REFERENCES: Shields 1960, Chapman and Harman 1972, Chapman 1974.





Desert Cottontail

M028 *(Sylvilagus audubonii)*

STATUS: No official listed status. Widespread; common game species.

DISTRIBUTION/HABITAT: Found only along western and southern edges of the Sierra Nevada at lower elevations of grasslands, chaparral, oak savannah, and early successional stages of digger pine-oak. Avoids dense stands; prefers areas of mixed grass and brush.

SPECIAL HABITAT REQUIREMENTS: Dense cover in scattered patches.

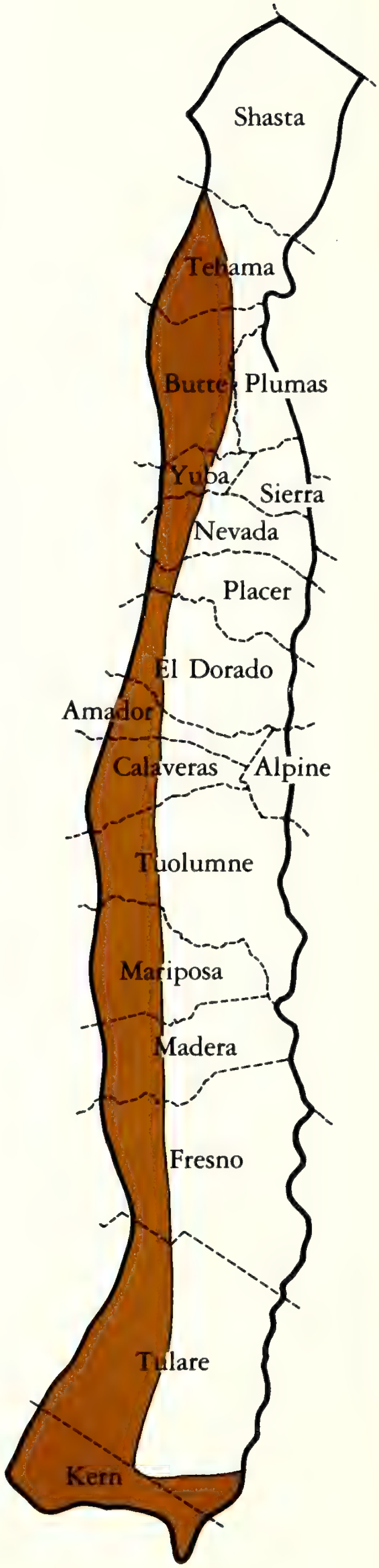
BREEDING: Two to four litters per year (average of 3 or 4 young in each, 6 not uncommon). Breeds from October through June, with peak activity from March to May. Nests in burrows or in cover on the ground.

TERRITORY/HOME RANGE: Probably not territorial. Sedentary animals; home ranges average from 7.4 to 9.9 acres (3 to 4 ha). In Madera County, range seldom more than 14.8 acres (6 ha) (Fitch 1947).

FOOD HABITS: Eats grasses (brome, fescue) and forbs (filaree, clover, tarweed, turkey mullein) obtained by feeding on the ground, usually near cover.

OTHER: Crepuscular and active all year. Found in more open habitats than *S. bachmani*.

REFERENCES: Ingles 1941, 1965; Fitch 1947.



Snowshoe Hare

M029 *(Lepus americanus)*

STATUS: No official listed status. A game species, protected by closed season and bag limits. Varies from common to uncommon.

DISTRIBUTION/HABITAT: Found in higher elevational zones of the middle and northern Sierra Nevada in riparian deciduous, alpine meadows, and conifer forests. Prefers earlier successional stages in pine or fir stands.

SPECIAL HABITAT REQUIREMENTS: Thickets of alder, willow, young conifers, or ceanothus-manzanita chaparral, and hollow logs.

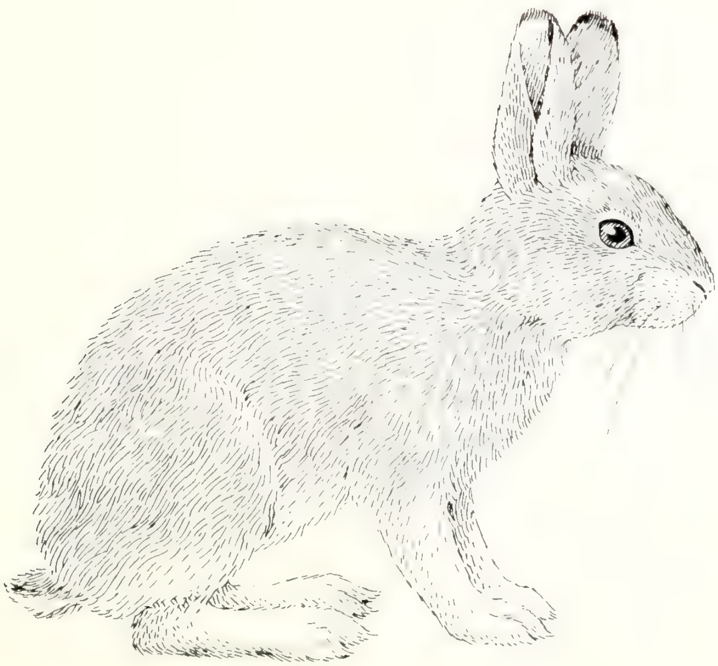
BREEDING: One to three litters per year; each litter contains 2 to 4 (as many as 8) young. Breeds from March to August, with peak in May and June. Gestation about 37 days. Open nests of grass and fur in depressions in ground.

TERRITORY/HOME RANGE: May be territorial during breeding season, but this not well established. In Alaska, home ranges varied from 9.9 to 24.7 acres (4.0 to 10.0 ha) with averages of 12.3 to 14.8 acres (5 to 6 ha) (O'Farrell 1965).

FOOD HABITS: Eats grasses, forbs, and shrubs; twigs and bark of shrubs and young trees eaten in winter. Feeds in meadows and other openings and at forest edges.

OTHER: Crepuscular and active all year. Most molt to a white coat in winter and a brown coat in summer.

REFERENCES: Adams 1959, O'Farrell 1965, Ingles 1965.



White-tailed Jackrabbit

M030 *(Lepus townsendii)*

STATUS: No official listed status. A game species not taken in large numbers by hunters. Uncommon in California; geographic range small.

DISTRIBUTION/HABITAT: Limited to the high Sierra Nevada (and the eastern slope). Found in all stages of red fir and lodgepole pine forests, but prefers early grass-forb successional stages. Alpine and mountain meadows important habitats.

SPECIAL HABITAT REQUIREMENTS: Scattered shrubs in open areas.

BREEDING: Usually one litter of 3 to 6 young (average of 4) per year. No burrows used; young concealed in vegetation. Gestation 43 days.

TERRITORY/HOME RANGE: Unknown.

FOOD HABITS: Eats mainly shrubs (cream bush, sagebrush, and others) in winter and spring, grasses and forbs in summer and fall.

OTHER: Mainly nocturnal; occasionally diurnal. Migrates to lower elevations in winter. More selective in food habits than black-tailed jackrabbits, thus giving the latter species a competitive advantage where both occur. Populations fluctuate in certain areas, but average densities of $21/mi^2$ ($8/km^2$) recorded in Colorado (Flinders and Hansen 1972).

REFERENCES: Orr 1940, Bear and Hansen 1966, Flinders and Hansen 1972.

Black-tailed Jackrabbit

M031 *(Lepus californicus)*

STATUS: No official listed status. Common species with widespread range. Increasing in popularity as game species.

DISTRIBUTION/HABITAT: Found in all elevational zones of the Sierra Nevada. Not found in pine or fir forests, except in early successional stages of grasses, shrubs, and seedlings. Prefers open grasslands or early stages of chaparral.

SPECIAL HABITAT REQUIREMENTS: Scattered shrubs in open areas.

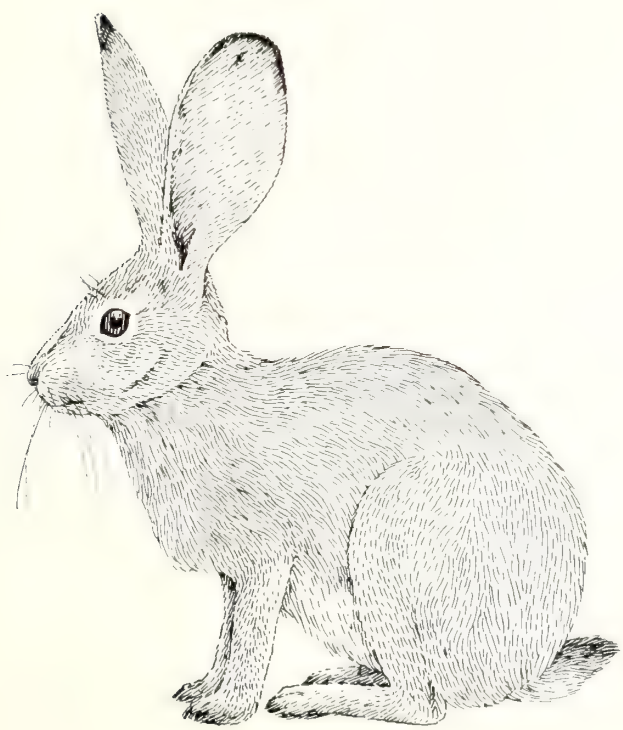
BREEDING: Breeds all year, but peak is from March to June. Usually more than one litter per year (3 or 4 young per litter). Nests placed under shrubs and in dense stands of grass; burrows not generally used. Gestation about 43 days.

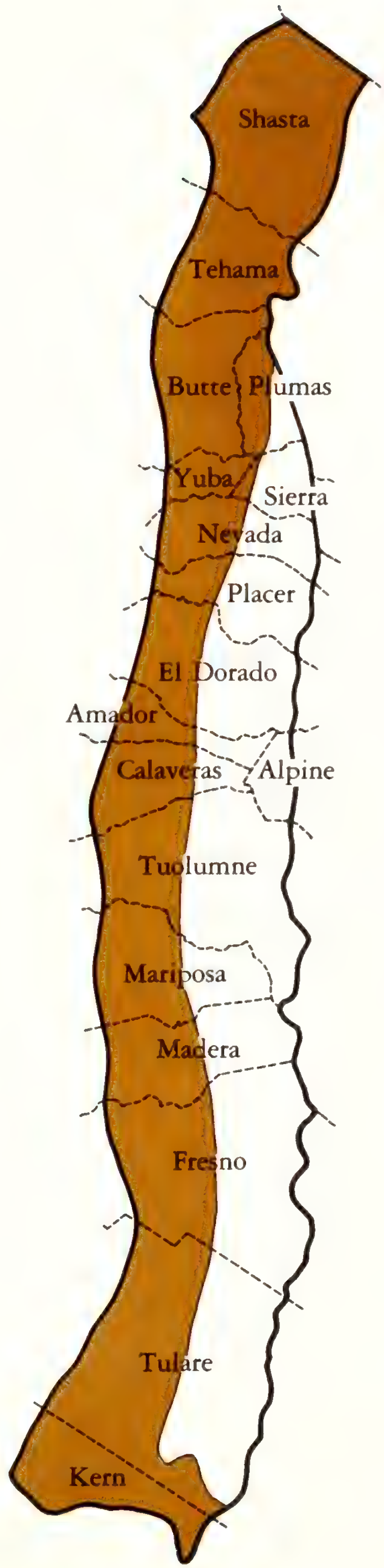
TERRITORY/HOME RANGE: Home ranges probably 4.9 to 24.7 acres (2 to 10 ha), but not well documented. Not territorial.

FOOD HABITS: Eats many kinds of grasses, forbs, shrubs, and cultivated crops.

OTHER: Crepuscular, diurnal, and active all year. An important food source for coyotes and some raptors, as densities may reach 260/mi^2 (100/km^2), based on study in Utah (Flinders and Hansen 1972).

REFERENCES: Orr 1940, Lechleitner 1958, Flinders and Hansen 1972.





Mountain Beaver

M032 *(Aplodontia rufa)*

STATUS: No official listed status. Scattered distribution and uncommon in the Sierra Nevada.

DISTRIBUTION/HABITAT: Prefers riparian habitats with thick undergrowth. Also found in wooded areas, old burns, and logged areas with considerable herbaceous growth. Not aquatic.

SPECIAL HABITAT REQUIREMENTS: Thick vegetation near water.

BREEDING: Breeds in March and April (mean litter size 3 or 4). Only one litter per year. Gestation 28 to 30 days. Young born in nest in burrow, located 1 to 5 ft (0.3 to 1.5 m) below ground, in area heavily overgrown with vegetation and strewn with rocks, or fallen logs, or both.

TERRITORY/HOME RANGE: Home range small; varied from 0.1 to 0.5 acre (0.04 to 0.2 ha) (mean of 0.25 acre [0.1 ha]) near Montesano, Washington (Martin 1971). Territoriality not known.

FOOD HABITS: Cuts vegetation to take to burrows; some food stored in hay piles. Occasionally climbs trees and clips branches or strips bark, but main food items are shrubs and forbs—thimbleberry, blackberry, dogwood, ferns, and lupine. Main foraging in heavy undergrowth, in burrows, and on ground surface.

OTHER: Active all year.

REFERENCES: Godin 1964, Ingles 1965, Martin 1971.

Alpine Chipmunk

M033 *(Eutamias alpinus)*

STATUS: No official listed status. Restricted in range, but common.

DISTRIBUTION/HABITAT: Geographic range limited to the high Sierra Nevada, in lodgepole pine forests, but generally above timberline in alpine meadows. Prefers talus slopes, areas of stunted pines (krumholz), and downed logs.

SPECIAL HABITAT REQUIREMENTS: Talus and downed logs.

BREEDING: Little information available; most breeding probably in July. Litter size from 3 to 6; one litter per year.

TERRITORY/HOME RANGE: Little information available. Probably territorial, defending immediate area of nests. Usually nests within crevices of talus slopes and other rocky areas.

FOOD HABITS: Feeds on seeds of sedges, grasses, and pines; also eats fungi. Feeds on ground and among logs and rocks; caches food.

OTHER: Hibernates from November to April; may be active day and night in summer.

REFERENCES: Grinnell and Storer 1924, Johnson 1943, Heller 1971, Heller and Gates 1971, Heller and Poulson 1972.

Least Chipmunk

M034 *(Eutamias minimus)*

STATUS: No official listed status. Restricted distribution in the western Sierra Nevada, but common in the eastern Sierra Nevada and Great Basin.

DISTRIBUTION/HABITAT: Found in two small areas near the Sierra Nevada Crest in Fresno and Tulare Counties, in lodgepole pine forests and alpine meadows in dry, exposed habitats.

SPECIAL HABITAT REQUIREMENTS: Open areas with stumps, logs, or rocks, and with brush.

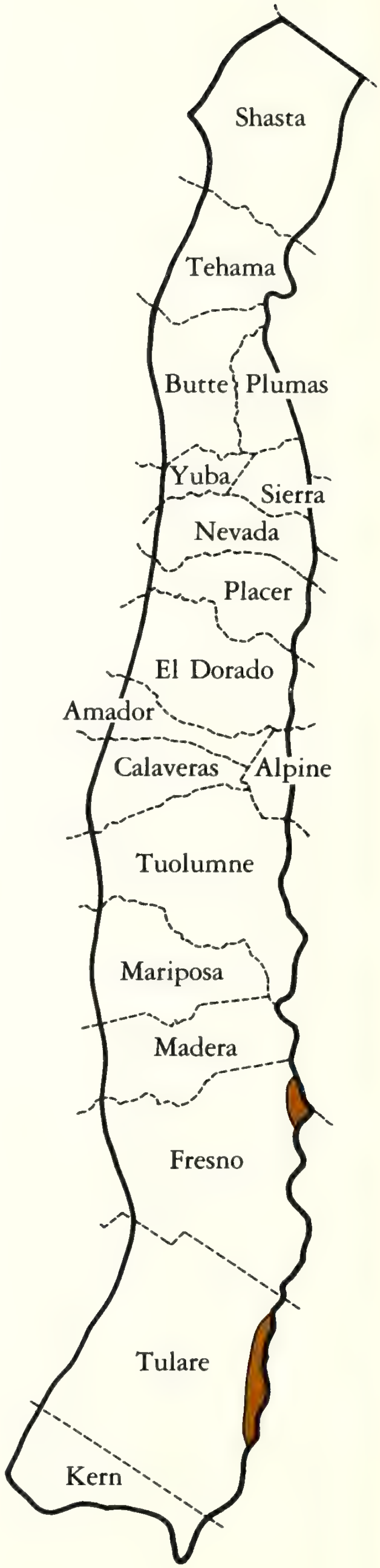
BREEDING: Breeds in June and July, little data available. Litter size from 3 to 8 (average 6). One litter per year. Nests found under stumps, logs, or rocks.

TERRITORY/HOME RANGE: Little information available; probably territorial, defending vicinity of nests. Home ranges varied from 0.5 to 3.7 acres (0.2 to 1.5 ha) in Montana (Martinsen 1968).

FOOD HABITS: Eats seeds, nuts, and fruits, and some insects. Searches for food on the ground, among rocks, logs, and stumps and in low shrubs. Caches food.

OTHER: Hibernates from November to April; may be active day and night.

REFERENCES: Ingles 1965, Forbes 1966, Martinsen 1968.



Yellow Pine Chipmunk

M035 *(Eutamias amoenus)*

STATUS: No official listed status. Common resident of the Sierra Nevada.

DISTRIBUTION/HABITAT: Widespread in all pine and fir forests from ponderosa pine to lodgepole pine. Prefers shrub-seedling-sapling stages of all timber types. Most abundant in open ponderosa pine forests.

SPECIAL HABITAT REQUIREMENTS: Shrubs, slash piles, or stumps in open forests.

BREEDING: Breeds from April to July, with peak activity in May and June. Litter size 4 to 8. One litter per year born in underground burrows. Gestation about 1 month.

TERRITORY/HOME RANGE: Home ranges in the Cascade Mountains averaged 1.0 to 3.8 acres (0.4 to 1.5 ha) (Broadbooks 1970b). Defends area immediately surrounding den.

FOOD HABITS: Feeds mainly on seeds of conifers, shrubs, forbs, and grasses. Some fungi, fruit, and insects also eaten. Forages primarily on ground, but occasionally climbs trees. Stores food in caches underground for use during winter. Cheek pouches used to carry food to storage sites.

OTHER: Often found associated with the golden-mantled ground squirrel.

REFERENCES: Johnson 1943; Broadbooks 1958, 1970a, 1970b; Heller 1971; States 1976.

Allen's Chipmunk

M036 (*Eutamias senex*)

STATUS: No official listed status. Uncommon to common in different areas of the Sierra Nevada.

DISTRIBUTION/HABITAT: Widespread in all coniferous forests. Prefers dense chaparral and forested areas with substantial shrub understories.

SPECIAL HABITAT REQUIREMENTS: Needs brush and logs, stumps, snags, rocks, or litter.

BREEDING: Unknown.

TERRITORY/HOME RANGE: Unknown.

FOOD HABITS: Unknown.

OTHER: Diurnal; probably hibernates from November to March. Specifically distinct from *E. townsendii* (Sutton and Nadler 1974). Little recorded on biology of species.

REFERENCES: Tevis 1956, Ingles 1965, Storer and Usinger 1971, Sutton and Nadler 1974.

Sonoma Chipmunk

M037 *(Eutamias sonomae)*

STATUS: No official listed status. Common within its range.

DISTRIBUTION/HABITAT: Range barely extends into the western Sierra Nevada in northern Shasta County. Prefers dense chaparral and shrub-seedling-sapling stages of digger pine-oak, black oak woodland, and ponderosa pine forests.

SPECIAL HABITAT REQUIREMENTS: Trees-shrubs; logs, stumps, snags, rocks, or litter.

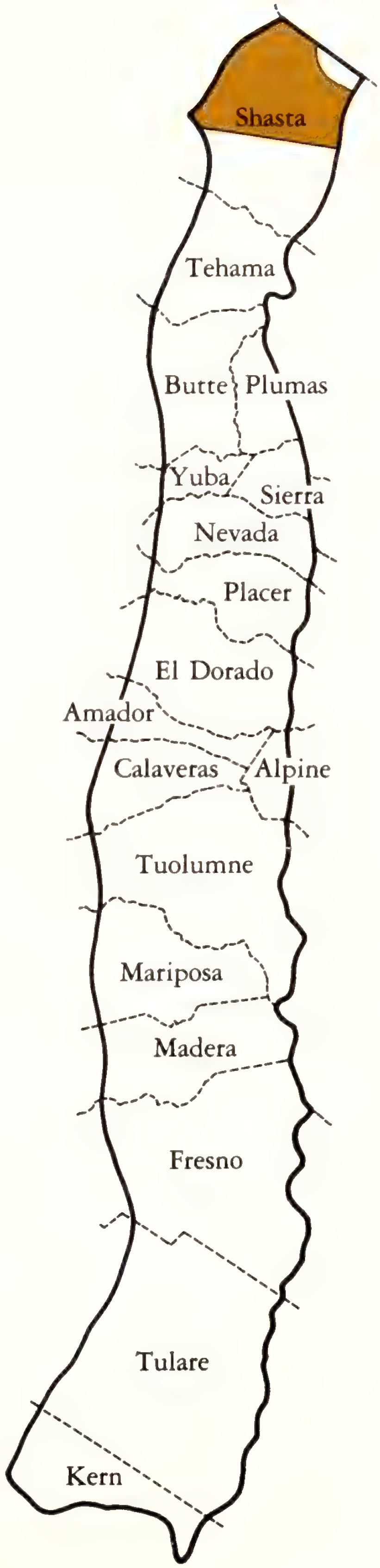
BREEDING: Breeds from February to July. Individuals mature at 1 year. One litter of 3 to 7 per year. Nests in logs, stumps, and burrows. Gestation about 1 month.

TERRITORY/HOME RANGE: Unknown.

FOOD HABITS: Feeds on acorns, fungi, and seeds of shrubs—manzanita, ceanothus, and gooseberry. Searches for food on the ground; food cached in many different places (scatter hoarding). Seeds often buried.

OTHER: Diurnal when active, but den-up during cold spells in winter. Primarily found along coast where populations coevolved with coastal chaparral plant communities.

REFERENCES: Johnson 1943, Ingles 1965, Smith 1977.



Merriam's Chipmunk

M038 (*Eutamias merriami*)

STATUS: No official listed status. Locally common at lower elevations in the southern Sierra Nevada.

DISTRIBUTION/HABITAT: Widespread from Tuolumne to Kern Counties. Found in all plant communities with substantial shrub understory from blue oak savannah to Jeffrey pine. Prefers heavy brush with associated oaks and rock outcrops.

SPECIAL HABITAT REQUIREMENTS: Trees-shrubs; logs, stumps, snags, rocks, or litter.

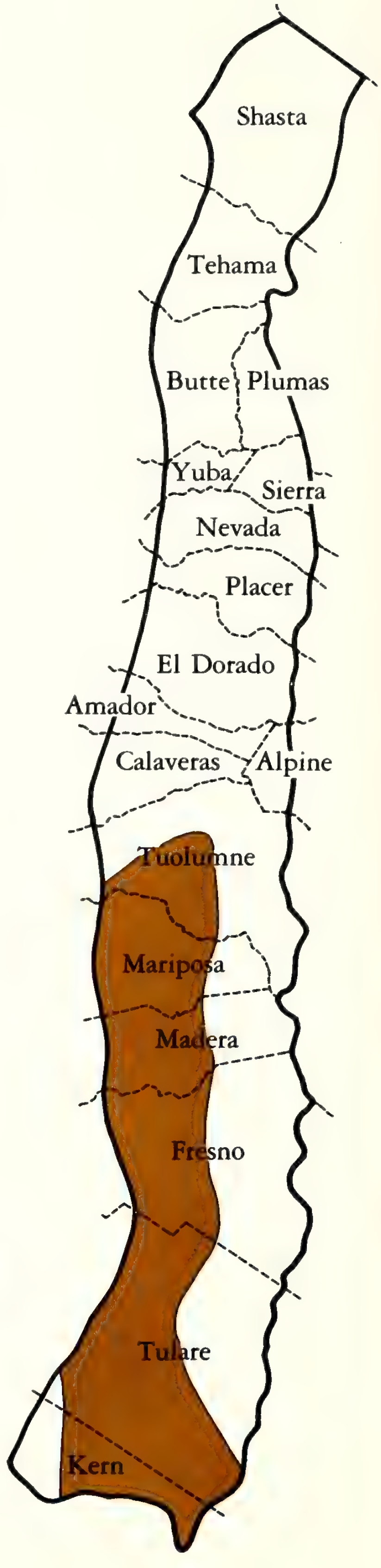
BREEDING: Breeds from April to June. Individuals sexually mature at 1 year and produce one litter of 3 to 8 per year. Nests found in rotting logs, stumps, and in burrows. Gestation about 1 month.

TERRITORY/HOME RANGE: Solitary; probably defends the area in immediate vicinity of den. Home range size unknown.

FOOD HABITS: Feeds on acorns and seeds of manzanita and other chaparral species. Searches for and gathers food on the ground, in shrubs, and on stumps, logs, and dead trees. Caches for later use.

OTHER: Unlike other *Eutamias* species in the Sierra Nevada, competing species absent over most of range (Callahan 1977).

REFERENCES: Swarth 1919, Grinnell and Storer 1924, Johnson 1943.



Long-eared Chipmunk

M039 *(Eutamias quadrimaculatus)*

STATUS: No official listed status. Uncommon to common in different parts of range.

DISTRIBUTION/HABITAT: Widespread in higher chaparral areas, and in ponderosa pine and mixed-conifer forests. Usually associated with patches of brush with substantial canopy cover.

SPECIAL HABITAT REQUIREMENTS: Logs, stumps, snags, rocks, or litter.

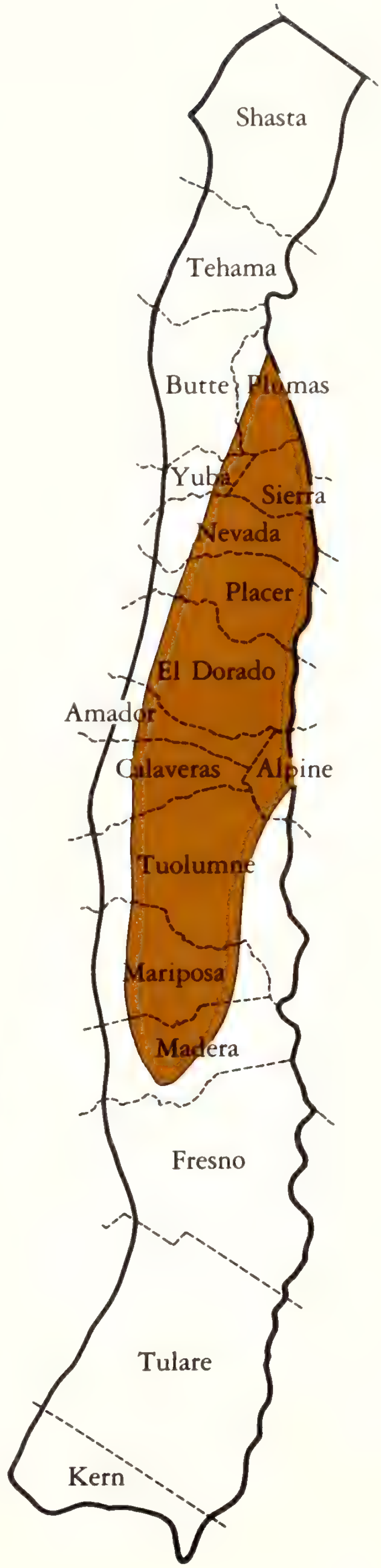
BREEDING: Breeds in May and June. Litter size averages 4 (range 3 to 8). Nests in trees, logs, stumps, and cavities of snags. Gestation about 1 month; one litter per year.

TERRITORY/HOME RANGE: Solitary and probably territorial in vicinity of nest. Home ranges in Madera County varied from 0.74 to 4.9 acres (0.3 to 2.0 ha) (Storer *et al.* 1944).

FOOD HABITS: Eats primarily seeds, fruits, and fungi. Searches for food on ground, in shrubs, and on logs, stumps, and snags. Caches food for later use.

OTHER: Diurnal when active; hibernates from November to March.

REFERENCES: Holdenreid 1940, Storer *et al.* 1944, Tevis 1955, Sutton and Dunford 1974.



Lodgepole Chipmunk

M040 (*Eutamias speciosus*)

STATUS: No official listed status. Common over range in the Sierra Nevada.

DISTRIBUTION/HABITAT: Widespread in mixed-conifer, Jeffrey pine, red fir, and lodgepole pine forests. Prefers pole-medium tree and large tree stages of coniferous forests.

SPECIAL HABITAT REQUIREMENTS: Trees-shrubs; logs, stumps, snags, rocks, or litter.

BREEDING: Breeds in June and July. Litter size averages 5 (range 3 to 7). Nests found in logs, stumps, and hollows in trees and snags. Gestation about 1 month; one litter per year.

TERRITORY/HOME RANGE: Probably territorial in immediate vicinity of nest. Home ranges in the Sierra Nevada varied form 2.5 to 4.9 acres (1.0 to 2.0 ha) (Roberts 1962).

FOOD HABITS: Eats fungi, flowers, and seeds of shrubs, forbs, grasses, and pines. Searches for food and harvests on ground, in shrubs and trees, and in logs and stumps. Caches food in trees or buries for later use.

OTHER: Diurnal when active; hibernates from November to March. Densities of up to 2/acre (5/ha) reported. Never far from trees; expert climbers. Burying seeds aids in reforestation.

REFERENCES: Orr 1949, Heller 1971, Heller and Gates 1971, Heller and Poulson 1972.

Yellow-bellied Marmot

M041 *(Marmota flaviventris)*

STATUS: No official listed status. Common and widespread in suitable habitats.

DISTRIBUTION/HABITAT: Found in the high Sierra Nevada, in Jeffrey pine, red fir, and lodgepole pine forests in association with rocky areas and meadows.

SPECIAL HABITAT REQUIREMENTS: Rocky outcrops or talus slopes; forest openings.

BREEDING: Breeds from March to July, with peak in May and June. Litter size from 3 to 8 (average of 4 to 6). One litter per year. Nests located in burrows among rocks or tree roots.

TERRITORY/HOME RANGE: Territory size ranges from 0.5 to 4.9 acres (0.2 to 2 ha) (mean of 1.2 to 1.7 acres [0.5 to 0.7 ha]). In Colorado, home range sizes varied from 4.9 to 24.7 acres (2 to 10 ha) (Armitage 1974).

FOOD HABITS: Forages in meadows and among rocks. Eats green grasses and forbs.

OTHER: Hibernates from October to April, living on accumulated fat deposits. Usually found in loose colonies; active day and night.

REFERENCES: Nee 1969, Armitage 1974, Barash 1974, Svendsen 1974.

Belding's Ground Squirrel

M042 *(Spermophilus beldingi)*

STATUS: No official listed status. Common throughout its high mountain range.

DISTRIBUTION/HABITAT: Restricted to high mountain habitats, primarily meadows and early successional stages of red fir and lodgepole pine forests.

SPECIAL HABITAT REQUIREMENTS: Forest openings with friable soils for burrowing.

BREEDING: Breeds from June to August, with peak in July. One litter per year averages 8 young (range 4 to 12). Young born in underground nest; burrows often dug between boulders.

TERRITORY/HOME RANGE: No data on territory. Home range size at Tioga Pass, Mono County, averaged 1.5 acres (0.6 ha) for males, and slightly smaller for females (Morton *et al.* 1974). Individuals usually found in colonies.

FOOD HABITS: Feeds on grasses, forbs, seeds, bulbs, and nuts. Forages on ground surface.

OTHER: Hibernates from September to April.

REFERENCES: Grinnell and Dixon 1919, Hall 1946, Morhardt and Gates 1974, Morton *et al.* 1974, Loehr and Risser 1977.

California Ground Squirrel

M043 *(Spermophilus beecheyi)*

STATUS: No official listed status. Common in the Sierra Nevada.

DISTRIBUTION/HABITAT: Widespread throughout almost all habitats and successional stages. Prefers openings and disturbed areas, particularly along roads and in grazed meadows.

SPECIAL HABITAT REQUIREMENTS: Forest openings and soil suitable for burrowing.

BREEDING: Breeds from April to July, with peak in May and June. One litter per year, with range of 3 to 15 young (mean of 6). Young remain underground for first 6 weeks of life.

TERRITORY/HOME RANGE: Probably not territorial. Home ranges vary from 1 to 4.9 acres (0.4 to 2.0 ha); individual home ranges may overlap considerably. Often lives in colonies; primarily active during day. Dens often found near rock outcrops.

FOOD HABITS: Varied diet. Feeds on fruits and seeds, twigs of shrubs and trees, stems and leaves of grasses and forbs, and some insects and carrion. Forages mainly on ground, but climbs bushes and small trees. Food stored for winter at high elevations, and for summer at low elevations.

OTHER: Hibernates at high elevations and estivates at lower elevations. Numbers increase with overgrazing or other disturbances that initiate secondary succession.

REFERENCES: Grinnell and Dixon 1919, Linsdale 1946, Fitch 1948b.

Golden-mantled Ground Squirrel

M044 (*Spermophilus lateralis*)

STATUS: No official listed status. Common throughout middle and higher elevations.

DISTRIBUTION/HABITAT: Widespread from ponderosa pine forests to alpine meadows. Prefers more open areas, reaching its greatest abundance in open forests lacking a dense understory.

SPECIAL HABITAT REQUIREMENTS: Logs, stumps, or rocks for ground cover.

BREEDING: Breeds from May to August, with peak in June and July. One litter per year averages 4 or 5 young (range 2 to 8).

TERRITORY/HOME RANGE: Little information; probably territorial. Home ranges from 1 to 2.5 acres (0.5 to 1.0 ha). Locates burrow entrances under rocks, stumps, and logs. Densities of 0.4 to 1.2/acre (1 to 3/ha) recorded.

FOOD HABITS: Variable diet, including nuts, seeds and fruits, insects and carrion, and grasses and herbs. Forages on the ground, in and on logs and stumps, and in shrubby vegetation. Transports food in cheek pouches, and stores it in food caches.

OTHER: Hibernates from October to April; may be active day and night during summer, although usually diurnal.

REFERENCES: Gordon 1943; Tevis 1955, 1956; McKeever 1946b; MacClintock 1970.

Western Gray Squirrel

M045 *(Sciurus griseus)*

STATUS: No official listed status. A game species locally common in the Sierra Nevada.

DISTRIBUTION/HABITAT: Found from the blue oak savannah up through Jeffrey pine forests along the entire length of the Sierra Nevada. Prefers mature stages of all plant communities.

SPECIAL HABITAT REQUIREMENTS: Mature trees and snags with nest cavities. Oak of some species required for permanent populations.

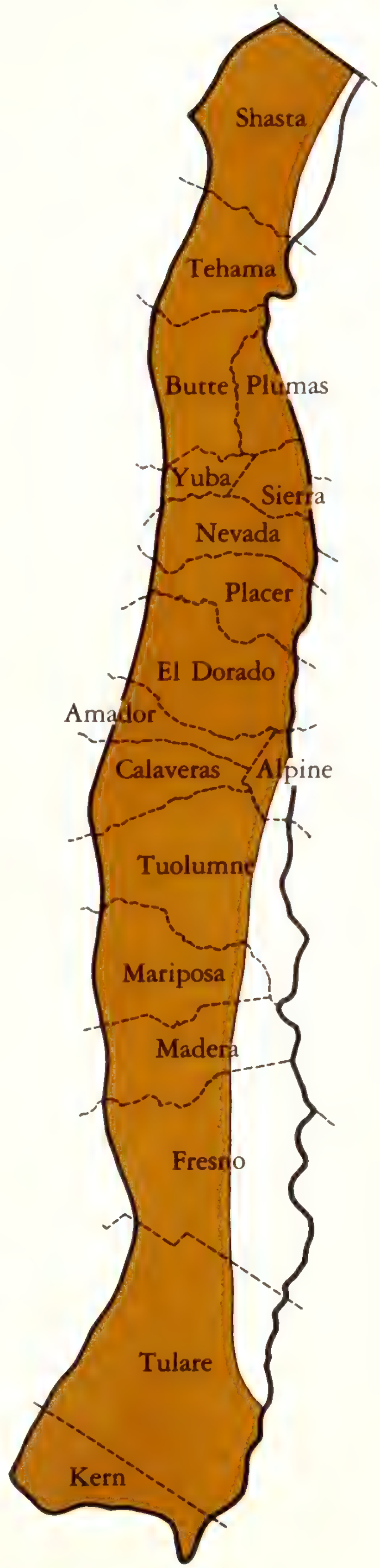
BREEDING: Breeds from February to June. Annual litter of 2 to 5 young born in late winter or early spring; gestation 44 days. Nests in holes in trees (winter) and outer branches of hardwoods (summer).

TERRITORY/HOME RANGE: Home ranges in the Sierra Nevada foothills varied from 0.5 to 1.8 acres (0.2 to 0.7 ha) for females, and from 1.3 to 2.5 acres (0.5 to 1.0 ha) for males (Ingles 1947). Lactating females incompatible, and defend territories of 0.3 to 0.8 acre (0.1 to 0.3 ha). Home ranges of males overlap considerably.

FOOD HABITS: Feeds mainly on acorns of California white oak and California black oak, and on pine seeds, green leaves, fungi, and mistletoe berries. Gathers food on ground and in trees. Stores some foods, especially acorns, for future use.

OTHER: Diurnal; does not hibernate. Densities of up to 1.6/acre (4/ha) recorded.

REFERENCES: Ingles 1947, Steinecker and Browning 1970, Asserson 1974.



Douglas' Squirrel

M046 (*Tamiasciurus douglasii*)

STATUS: No official listed status. A game species. Sparse to common in different areas of its range in the Sierra Nevada.

DISTRIBUTION/HABITAT: Widespread in all conifer forests from ponderosa pine up through lodgepole pine. Prefers large tree stages with substantial crown closure; avoids areas with considerable shrub understory.

SPECIAL HABITAT REQUIREMENTS: Snags or trees with nest holes; conifer seeds for food.

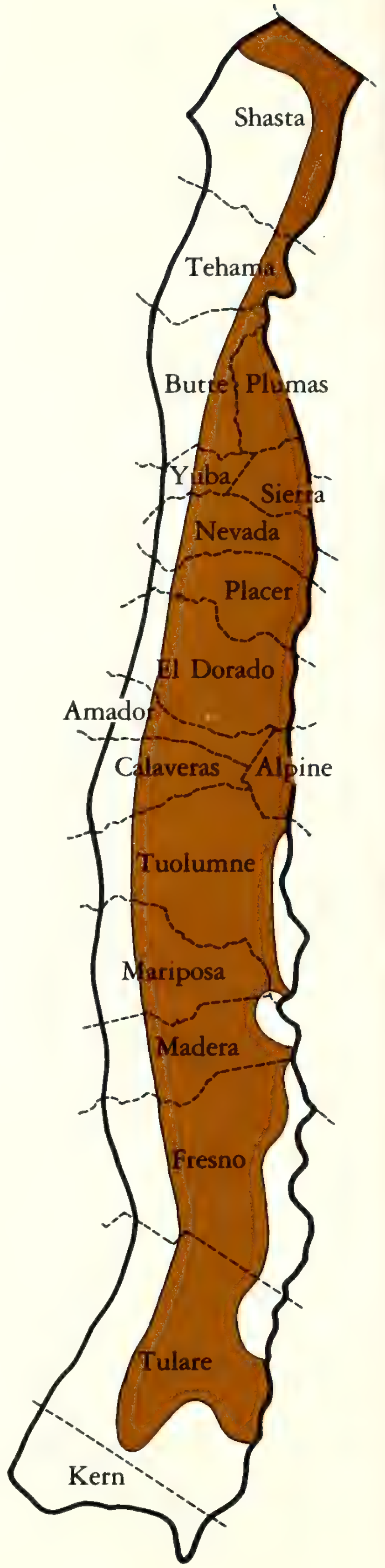
BREEDING: Breeds from May to October, with peak from April to July. Usually one litter per year (occasionally two); range from 3 to 8 young (average of 4 or 5). Nests in woodpecker holes or cavities in mature trees. Gestation 36 to 40 days.

TERRITORY/HOME RANGE: Territories in the central Sierra Nevada varied from 0.5 to 4.0 acres (0.2 to 1.6 ha) (Hartesveldt *et al.* 1970).

FOOD HABITS: Feeds mainly on conifer seeds, fungi, flowers, and leaf buds. Gathers food on ground and in trees, where cones are cut and dropped to ground. Defends food sources and places middens, for use during winter, in damp or wet sites. Conifer seeds the winter staple.

OTHER: Diurnal and active all year. Good habitat supports densities approaching 0.8/acre (2/ha).

REFERENCES: McKeever 1964a, Ingles 1965, Smith 1970.



Northern Flying Squirrel

M047 *(Glaucomys sabrinus)*

STATUS: No official listed status. Not a game species; may not be killed or captured, according to current regulations. Locally common in the Sierra Nevada.

DISTRIBUTION/HABITAT: Widespread from ponderosa pine through lodgepole pine forests. Prefers mature tree stages in all habitats.

SPECIAL HABITAT REQUIREMENTS: Snags and trees with nest holes.

BREEDING: Breeds in May and June. Litter size from 1 to 6 (average of 4). Nests in holes in trees.

TERRITORY/HOME RANGE: Home range size of a mother-young group in the Sierra Nevada was 4.9 acres (2 ha) (MacClintock 1970).

FOOD HABITS: Eats seeds, nuts and fruits, fungi, insects, and baby birds and eggs in summer; lichens and mosses important staples in winter. Searches for and gathers food on ground and in trees. Does not store food.

OTHER: Nocturnal; gregarious during winter. Glides for distances up to 150 ft (46 m). Furry membranes extend from ankles to wrists. Large owls prey on flying squirrels as they glide from tree to tree.

REFERENCES: Cowan 1936, Cowan and Guiguet 1965, MacClintock 1970.

Botta's Pocket Gopher

M048 *(Thomomys bottae)*

STATUS: No official listed status. Abundant throughout length of the Sierra Nevada below about 5000 ft (1520 m).

DISTRIBUTION/HABITAT: Widespread; found wherever soils friable. Prefers grass-forb stages of all communities.

SPECIAL HABITAT REQUIREMENTS: Friable soils deep enough for burrowing.

BREEDING: Breeds from October to June, with peak from March to May. Litter size 3 to 12 (average of 5). Up to three litters per year born in underground burrows; gestation 18 or 19 days.

TERRITORY/HOME RANGE: Territorial and solitary, except during breeding season.

FOOD HABITS: Herbivorous: feeds mainly on roots, tubers, bulbs, and stems and leaves of forbs and grasses. Shrubs and tree seedlings sometimes eaten, occasionally damaging to young conifer plantations.

OTHER: Active all year. Soil plugs, pushed into tunnels in snow, settle on surface during thaw and help retard runoff of snowmelt. Burrowing activities aid in mixing and building of forest and meadow soils. Densities may reach 1.6/acre (4/ha).

REFERENCES: Howard and Childs 1959, Ingles 1965, Barnes 1973, Capp 1976.

Mountain Pocket Gopher

M049 *(Thomomys monticola)*

STATUS: No official listed status. Abundant within its range in California.

DISTRIBUTION/HABITAT: Widespread at elevations above 5000 ft (1520 m). Inhabits meadows and open coniferous forests from the ponderosa pine zone to the Sierra Nevada Crest. Prefers grass-forb stages of all habitat types.

SPECIAL HABITAT REQUIREMENTS: Friable soil for burrowing; forest openings.

BREEDING: Mates from May to September, with peak from June to August. Litter size 2 to 8 (average of 3 or 4). Usually one litter per year.

TERRITORY/HOME RANGE: Pocket gophers in Fresno County had territories of up to 0.5 acre (0.2 ha) (Ingles 1952).

FOOD HABITS: Feeds underground on roots, tubers, and bulbs, and aboveground on stems and leaves of forbs and grasses. Shrubs and tree seedlings sometimes eaten, damaging young conifer plantations.

OTHER: Active all year. Soil pushed into tunnels in snow, exposed during spring thaw, helps retard runoff. Burrowing activities aid in mixing and building of soils, and percolation of water.

REFERENCES: Ingles 1949, 1952; Volland 1974.

Little Pocket Mouse

M050 (*Perognathus longimembris*)

STATUS: No official listed status

DISTRIBUTION/HABITAT: Limited to extreme southeastern portion of the Sierra Nevada in Kern and Tulare Counties. Found only in open grasslands bordering the Mojave Desert.

SPECIAL HABITAT REQUIREMENTS: Medium or large forest openings.

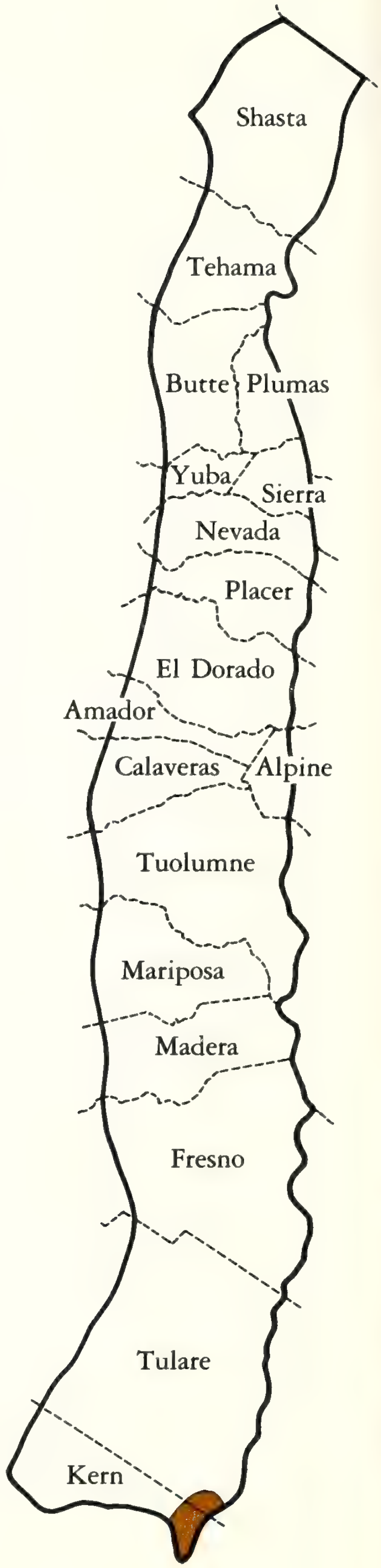
BREEDING: Breeds from April to September; one or two litters per year. Litter size 3 to 7 (average 4). Nests constructed in underground burrows.

TERRITORY/HOME RANGE: Territory unknown, but most species solitary. Home range averaged 0.8 acre (0.33 ha) in Nevada (O'Farrell 1978).

FOOD HABITS: Feeds primarily on the seeds of annual and perennial grasses and forbs; stores some for later use.

OTHER: Nocturnal. Plug burrow entrances during day. May hibernate in cold weather or when food is scarce.

REFERENCES: Hall 1946, Maza *et al.* 1973.



Great Basin Pocket Mouse

M051 *(Perognathus parvus)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Found only in extreme northeastern portion of Sierra Nevada. Primarily a Great Basin species, but found within ponderosa pine and Jeffrey pine forests in a small area of Shasta County. Prefers grass-forb stages of all plant communities.

SPECIAL HABITAT REQUIREMENTS: Friable soils and open areas.

BREEDING: Breeds from May to July, with peak of activity in June. Litter size 3 to 8 (average 5). Nests usually located in burrows under sagebrush or other shrubs.

TERRITORY/HOME RANGE: Unknown. Most species solitary.

FOOD HABITS: Feeds mostly on seeds of forbs, grasses, and shrubs. Insects eaten and may be principal food at times when abundant. Searches for and gathers food on ground; may store food in nest.

OTHER: Nocturnal; plugs entrances to burrows during day.

REFERENCES: Smith 1942, Hall 1946, Ingles 1965, O'Farrell 1975.

Yellow-eared Pocket Mouse

M052 *(Perognathus xanthonotus)*

STATUS: No official listed status. Common in limited area of Kern Gap.

DISTRIBUTION/HABITAT: Found only in extreme southeastern portion of the western Sierra Nevada, in vicinity of Walker Pass, Kern County. Undoubtedly more wide-ranging along eastern front of the southern Sierra Nevada, but no published records. Found on variety of soil types in open, grassy areas in piñon-juniper and Joshua tree associations. All known specimens collected between 4000 and 5300 ft (1220-1616 m) elevation.

SPECIAL HABITAT REQUIREMENTS: Open areas with friable soils for burrowing.

BREEDING: Unknown.

TERRITORY/HOME RANGE: Unknown.

FOOD HABITS: Unknown. In general, granivorous; but many pocket mice, including the closely related Great Basin pocket mouse, supplement diets with insects and young portions of grasses and forbs.

OTHER: Closely related to and possibly conspecific with populations of Great Basin pocket mouse, which ranges farther north along eastern front of the Sierra Nevada.

REFERENCES: Ingles 1965, Williams 1978.

California Pocket Mouse

M053 *(Perognathus californicus)*

STATUS: No official listed status. Common throughout its range in the Sierra Nevada.

DISTRIBUTION/HABITAT: Widespread at lower elevations from El Dorado to Kern Counties. Prefers brushy areas in digger pine-oak and chaparral communities.

SPECIAL HABITAT REQUIREMENTS: Friable soils; shrubs-grass-forbs.

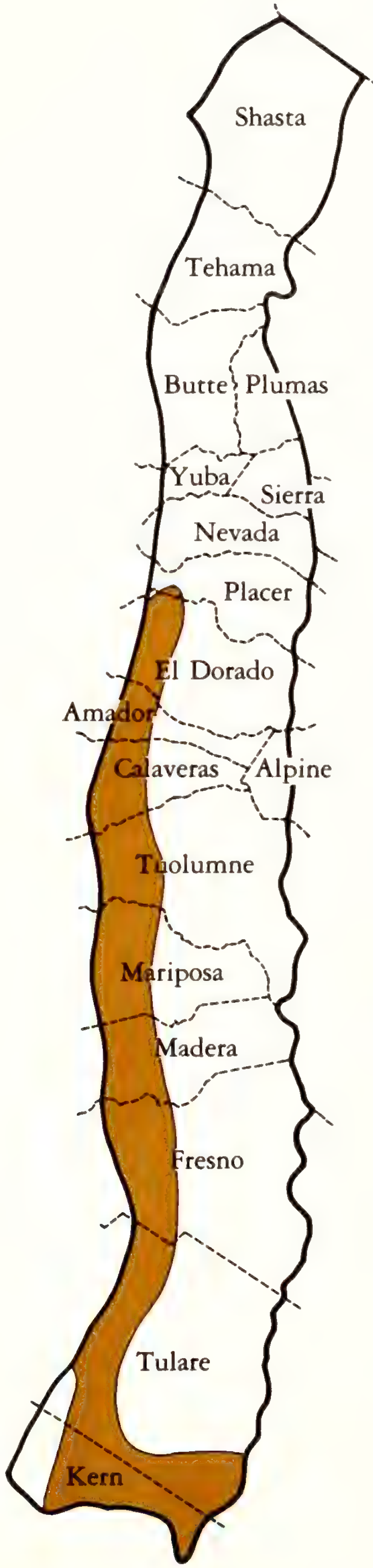
BREEDING: Breeds from April to July. Litter size 2 to 7; born in nests in burrows dug in soft soil.

TERRITORY/HOME RANGE: Unknown. Most species of pocket mice solitary.

FOOD HABITS: Feeds mostly on seeds of annual grasses and forbs. Searches for and gathers food on ground. Some food stored.

OTHER: Nocturnal; becomes torpid during cold weather or when food is scarce.

REFERENCES: Ingles 1965, Tucker 1966, Burt and Grossenheider 1976.



Heermann's Kangaroo Rat

M054 (*Dipodomys heermanni*)

STATUS: No official listed status. Locally common in its range in the Sierra Nevada.

DISTRIBUTION/HABITAT: Widespread at lower elevations. Prefers grass-forb stages of chaparral and oak-savannah. Favors bare ground; populations enhanced by fire and grazing.

SPECIAL HABITAT REQUIREMENTS: Friable soil; forest openings. Loose, dry earth near burrows required for "dusting" to keep fur from becoming excessively oily.

BREEDING: Breeds from February to August, with peak in April. Litter size 2 to 5 (average 4). Two or three litters per year common; females of first litter may have two litters of their own before winter. Nests in burrows that may have up to six entrances.

TERRITORY/HOME RANGE: Unknown. Most kangaroo rats solitary and territorial.

FOOD HABITS: Feeds on seeds, forbs, and green grasses. Some stored. Herbage eaten primarily during winter and spring. Can survive without drinking water.

OTHER: Nocturnal. Populations fluctuate widely from year to year; reach densities up to 6/acre (15/ha).

REFERENCES: Tappe 1941, Fitch 1948a, Patton *et al.* 1976.

California Kangaroo Rat

M055 *(Dipodomys californicus)*

STATUS: No official listed status. Common in suitable habitat within range in the Sierra Nevada.

DISTRIBUTION/HABITAT: Open areas generally below 1310 ft (400 m) in elevation, but found as high as about 4270 ft (1300 m) in dry, open sites in Shasta County. Usually found in grassland habitats, but also in clearings among chaparral on the lower slopes of foothills.

SPECIAL HABITAT REQUIREMENTS: No published information available for the western Sierra Nevada; requires friable soils in open habitats in southern Oregon (Bailey 1936). Soft, fine sands or loose, dry silts required for dust bathing.

BREEDING: In southern Oregon, breeds from April to September (Bailey 1936), but breeding season probably indicated earlier in southern part of range. Two to 4 young per litter.

TERRITORY/HOME RANGE: Unknown. Most kangaroo rats solitary and territorial.

FOOD HABITS: Eats primarily seeds. New growth of grasses and forbs apparently eaten. Berries and seeds of manzanita, ceanothus, rabbit bush, lupine, bur-clover, wild oats, and small tubers (unidentified) recorded from cheek pouches of individuals from Oregon.

OTHER: Considered a race of Heermann's kangaroo rat before report of Patton *et al.* (1976). The two species apparently not closely related. Inferences on biology of California kangaroo rat, based on studies of *D. Heermanni*, may not be valid.

REFERENCES: Bailey 1936, Patton *et al.* 1976.

Beaver

M056 *(Castor canadensis)*

STATUS: No official listed status. May be trapped only during designated season. Common as introduced populations in the Sierra Nevada.

DISTRIBUTION/HABITAT: Scattered colonies found in the central to northern Sierra Nevada, primarily at lower elevations. Restricted to riparian deciduous habitats along streams, ponds, lakes, and wet meadows.

SPECIAL HABITAT REQUIREMENTS: Sufficient amounts of permanent water near food supplies of aspen, willow, alder, or cottonwood.

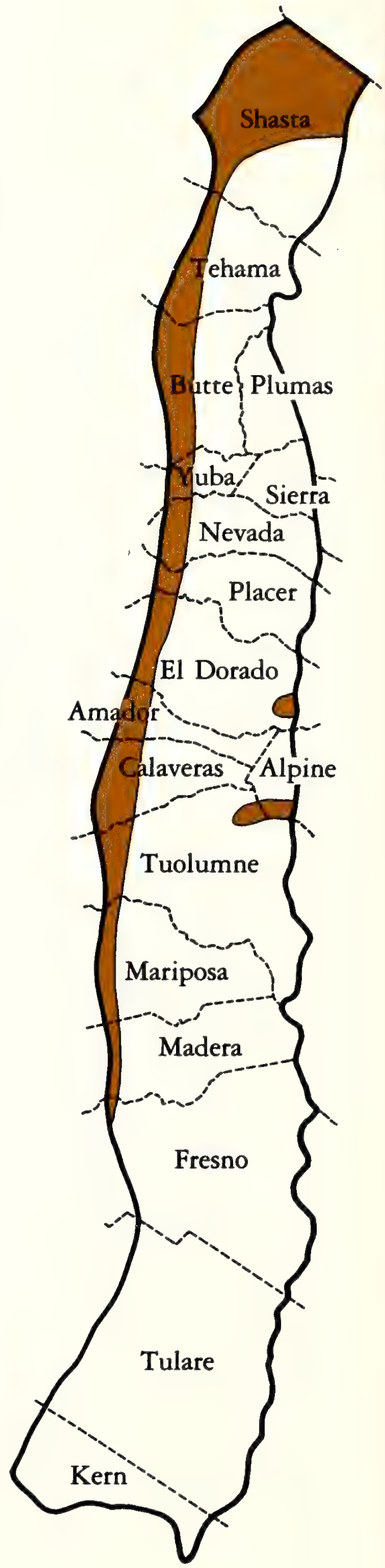
BREEDING: Breeds from April to July, with peak in May. Litter size 2 to 8 (average 3). Kits born in nests in holes in banks or in lodges built of sticks, twigs, and mud in ponds.

TERRITORY/HOME RANGE: In the MacKenzie Delta of Canada, home ranges as large as 494 acres (200 ha) (Aleksiuk 1968). Defended territories of 25 to 125 acres (10 to 50.5 ha).

FOOD HABITS: Eats cambial layers of aspen, cottonwood, alder, and willow in winter; leaves, grasses, roots, cattails, tules, and pond lillies in summer. Cuts trees and shrubs by gnawing. Stores food underwater for winter.

OTHER: Largest rodent in North America; active all year. Colonies often of family groups of paired adults, yearlings, and young of year. Deep water required where winter freezing occurs. Building of dams creates habitats for many species of wildlife. Dams not built where water deep.

REFERENCES: Tappe 1942, Hall 1960, Ingles 1965.



Western Harvest Mouse

M057 *(Reithrodontomys megalotis)*

STATUS: No official listed status. Rare to common in different areas of the Sierra Nevada.

DISTRIBUTION/HABITAT: Found at all elevations in grass-forb stages of all plant communities.

SPECIAL HABITAT REQUIREMENTS:

BREEDING: Breeds all year at lower elevations, and from early spring to late fall at higher elevations. Litter size 1 to 9 (average 4). Sexually mature at 2 months of age. Can produce five litters per year. Bird-like nests built in stands of grass or weeds and occasionally in woodpecker holes.

TERRITORY/HOME RANGE: Home range along California coast ranged from 0.5 to 1.7 acres (0.2 to 0.7 ha) and averaged 1.0 acre (0.4 ha) (Brant 1962).

FOOD HABITS: Searches for and gathers food on the ground and in bushes. Eats seeds and fruits of grasses, forbs, and shrubs.

OTHER: Nocturnal; often uses runways of meadow mice (voles) when foraging. Densities up to 13/acre (32/ha) recorded.

REFERENCES: Pearson 1960, Brant 1962, Ingles 1965.

California Mouse

M058 *(Peromyscus californicus)*

STATUS: No official listed status. Not common in the Sierra Nevada.

DISTRIBUTION/HABITAT: Found from southern Tuolumne County to Kern County, generally below 5000 ft (1520 m). Usually closely associated with distribution of California bay trees in mesic oak-woodland communities. Favors chaparral and other brushy communities.

SPECIAL HABITAT REQUIREMENTS: Trees-shrubs, rotten logs, litter, stumps, or snags.

BREEDING: Breeds all year, with peak activity from April to October. Litter size 1 to 3 (average 2). Several litters per year. Gestation 22 to 25 days. Often constructs stick nests, similar to those of woodrats.

TERRITORY/HOME RANGE: California mice in the San Francisco Bay area showed aggressive behavior near the nest (McCabe and Blanchard 1950).

FOOD HABITS: Eats primarily seeds, especially those of California bay tree, toyon berries, acorns, fungi, and insects. Gathers food by searching on the ground and in bushes and trees.

OTHER: Most specialized of the four species of deer mice found in the Sierra Nevada. A good climber; inefficient burrower; may be limited by availability of adequate cover. Densities up to 50/acre (125/ha) recorded in oak-laurel woodlands.

REFERENCES: McCabe and Blanchard 1950; Ingles 1965; Merritt 1974, 1978.

Deer Mouse

M059 (*Peromyscus maniculatus*)

STATUS: No official listed status. Most numerous native mammal in North America; common to abundant in the Sierra Nevada.

DISTRIBUTION/HABITAT: Found throughout the Sierra Nevada in all plant communities and successional stages.

SPECIAL HABITAT REQUIREMENTS:

BREEDING: Breeds from March to December, with peak from May to September. Litters born in grass-lined nests in rotting logs, among rocks, and in burrows; range from 3 to 7 young (average 5). Gestation 22 to 25 days; three or four litters per year.

TERRITORY/HOME RANGE: Home ranges averaged 0.25 to 0.50 acre (0.1 to 0.2 ha) (Storer *et al.* 1944).

FOOD HABITS: Eats primarily seeds, fruits, leaves, insects, and fungi. Insects most important in spring. Gathers food primarily on ground; large caches stored for winter use.

OTHER: An integral part of the forest food chain—serves as prey for raptors, snakes, and predatory mammals. Nocturnal; active all year. Exerts important controls on populations of insect pests of forest trees. Densities can reach 25 to 62/acre (10 to 25/ha). Where reduction of natural predators leads to population buildups, can become serious pests.

REFERENCES: Storer *et al.* 1944, Jameson 1952, King 1968, Sadleir 1974.

Brush Mouse

M060 *(Peromyscus boylii)*

STATUS: No official listed status. Common to abundant in its range in the Sierra Nevada.

DISTRIBUTION/HABITAT: Found throughout the Sierra Nevada, from mixed-conifer belt down through blue oak savannah. Avoids open meadows, grasslands, and areas lacking a substantial shrub understory. Prefers shrub-seedling-sapling stage of all habitat types.

SPECIAL HABITAT REQUIREMENTS: Trees-shrubs; logs, litter, or rocks necessary for excape cover and nesting sites.

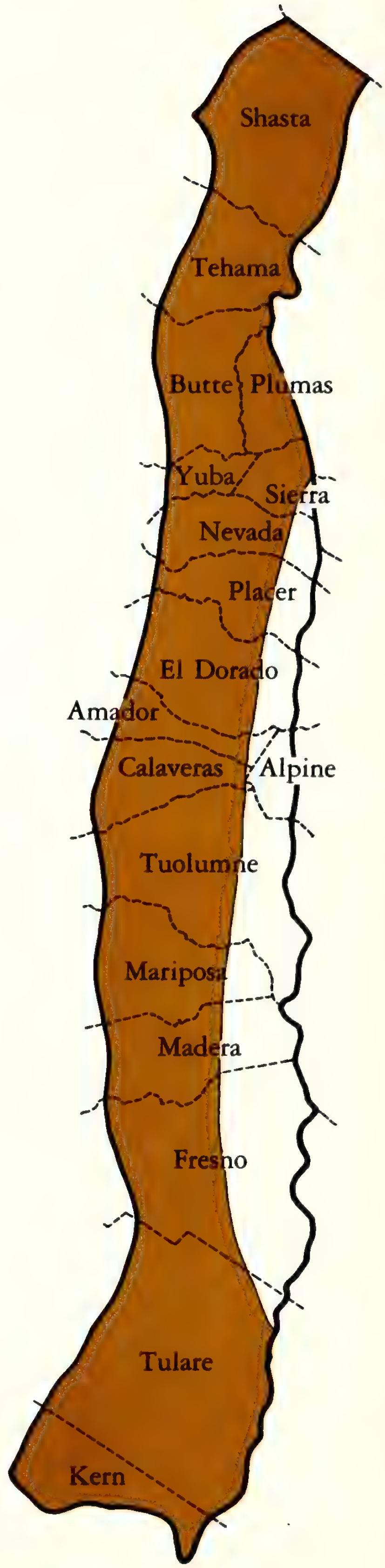
BREEDING: Mates from early April to mid-July, with peak during June. Gestation 22 to 25 days. Litters of 2 to 5 (average 3 or 4) born in grass-lined nests in rotting logs, burrows, or among rocks. One to three litters per year.

TERRITORY/HOME RANGE: Home ranges averaged 0.25 to 0.50 acre (0.1 to 0.2 ha) at Bass Lake, Madera County (Storer *et al.* 1944).

FOOD HABITS: Eats seeds, leaves, fungi, fruits, and insects; forages among ground litter.

OTHER: Nocturnal. Provides part of the diet of raptors, snakes, and many predatory mammals. Active all year; serves as important biological control of some insect pests of forest trees.

REFERENCES: Storer *et al.* 1944, Jameson 1951, Ingles 1965.



Piñon Mouse

M061 *(Peromyscus truei)*

STATUS: No official listed status. Widespread; common throughout range in California.

DISTRIBUTION/HABITAT: Abundant in woodland and brushland habitats below ponderosa pine forests. Generally limited to habitats containing some species of pygmy conifer.

SPECIAL HABITAT REQUIREMENTS: Thickets of brush, or small trees or rocks, or both.

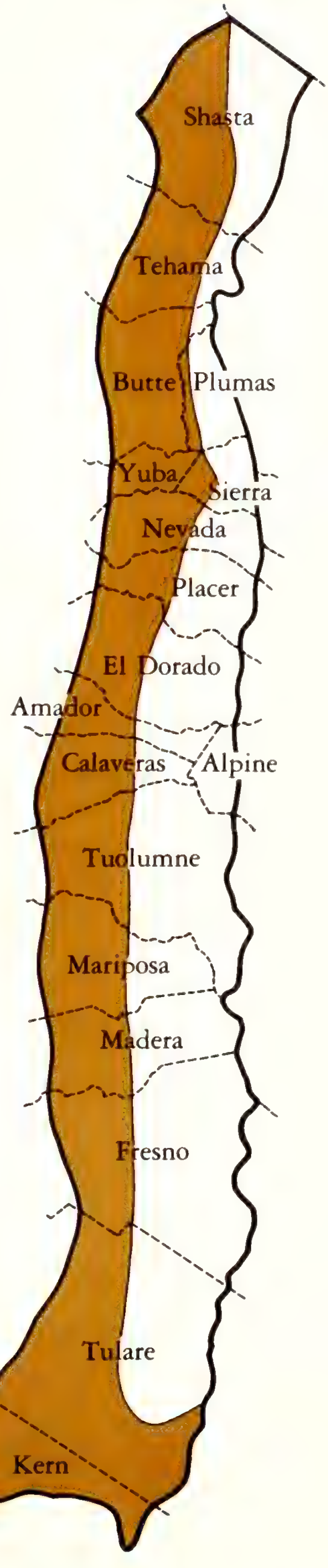
BREEDING: Breeds from March to June. One litter per year; litter size 3 to 6 (average 4). Nests in trash or holes in trees, among brush, or in rock crevices.

TERRITORY/HOME RANGE: In Colorado, mean home range size 1.1 acres (0.45 ha) (Douglas 1969). Territory restricted to vicinity of nest (McCabe and Blanchard 1950).

FOOD HABITS: Forages on ground and in shrubs; sometimes caches food. Eats primarily seeds, insects, acorns, and leaves.

OTHER: Nocturnal; often climbs small trees to forage, nest, and escape from predators. Population densities from 1/acre (2.5/ha) in oak-bay woodlands to 35/acre (60/ha) in chaparral (Merritt 1974).

REFERENCES: McCabe and Blanchard 1950, Lawrence 1966, Douglas 1969, Merritt 1974.



Dusky-footed Woodrat

M062 *(Neotoma fuscipes)*

STATUS: No official listed status. Common throughout range in California.

DISTRIBUTION/HABITAT: Widespread along entire western slope of the Sierra Nevada, from digger pine-oak belt up through mixed-conifer forests. Avoids cultivated land, open grassland, and pure chaparral stands.

SPECIAL HABITAT REQUIREMENTS: Trees-shrubs; litter for building nest houses.

BREEDING: Breeds from March to September, with peak in May and June. Litter size 1 to 4 (average 2 or 3). Large stick nests located either on ground or in trees.

TERRITORY/HOME RANGE: Home ranges not larger than 1.25 acres (0.5 ha) at Hastings Reserve, Monterey County (Linsdale and Tevis 1951).

FOOD HABITATS: Searches ground for acorns, fruits, seeds, grasses, forbs, and fungi. Also eats stems and leaves of shrubs. Climbs trees in search of browse.

OTHER: Active all year. Stick-nest piles may be 6 ft (1.8 m) high and may provide shelter for many other species of animals.

REFERENCES: Vestal 1938, Linsdale and Tevis 1951, Hooven 1959, Cranford 1977.

Bushy-tailed Woodrat

M063 *(Neotoma cinerea)*

STATUS: No official listed status. Common within range in California.

DISTRIBUTION/HABITAT: Widespread in suitable rocky habitat in upper elevation coniferous forests. Prefers early successional stages of Jeffrey pine, red fir, and lodgepole pine forests.

SPECIAL HABITAT REQUIREMENTS: Talus slopes and other rocky areas for nest sites.

BREEDING: Breeds from April to September, with peak in June and July. Average 3 young per litter (range 2 to 4). Rock crevices usually selected as nest sites.

TERRITORY/HOME RANGE: Sedentary; remains close to den year-round.

FOOD HABITS: Gathers fruits, nuts, berries, and fungi; also eats stems and leaves of shrubs and herbs.

OTHER: Primarily nocturnal; active all year. Frequently prey of owls, snakes, and predatory mammals. Nests often constructed of huge piles of litter, dung, bones, and other objects.

REFERENCES: Dixon 1919, Ingles 1965.

Western Red-backed Vole

M064 *(Clethrionomys occidentalis)*

STATUS: No official listed status.

DISTRIBUTION/HABITAT: Restricted to altitudes between 3600 to 6235 ft (1100 to 1900 m). Associated with conifer forests having abundant ground cover and litter. Spotty distribution within this region.

SPECIAL HABITAT REQUIREMENTS: Logs, snags, stumps, or other litter.

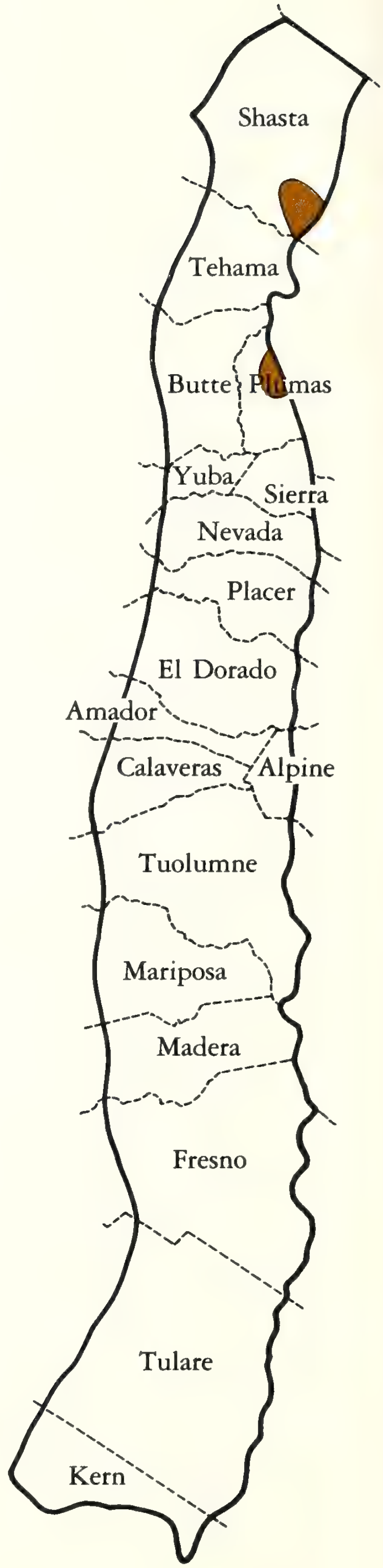
BREEDING: Breeds from June to August. Litter size 2 to 4. Nests placed under logs, roots, or boulders.

TERRITORY/HOME RANGE: Unknown.

FOOD HABITS: Eats primarily green vegetation, twigs, seeds, fungi, and insects. Forages on ground and in low shrubs.

OTHER: Primarily nocturnal. Densities may reach 4/acre (10/ha).

REFERENCES: Tevis 1956, Gashwiler 1959, Ingles 1965.



Heather Vole

M065 *(Phenacomys intermedius)*

STATUS: No official listed status. Uncommon within its range.

DISTRIBUTION/HABITAT: Found in alpine and subalpine areas at elevations of 6562 to 9843 ft. (2000 to 3000 m). Associated plants include heathers and huckleberries.

BREEDING: Breeds from June to September. Mean litter size 5 (range 2 to 8). Females breed in first year; males do not breed until second year.

TERRITORY/HOME RANGE: Unknown.

FOOD HABITS: Forages on the ground; caches some food. Eats primarily bark and twigs of willow and other shrubs during winter; herbaceous plants, seeds, berries, and twigs in summer.

OTHER: Builds grass nests under snow in winter.

REFERENCES: Shaw 1924, Edwards 1955, Foster 1961.

Montane Vole

M066 *Microtus montanus*)

STATUS: No official listed status. Widespread within the Sierra Nevada and common in some locations.

DISTRIBUTION/HABITAT: Ranges in altitude from 4900 to 12,500 ft. (1500 to 3800 m); found in wet areas and mountain meadows.

SPECIAL HABITAT REQUIREMENTS: Grasses or sedges, or both.

BREEDING: Breeds from March to November. More than one litter per year. Mean litter size 5 (range 1 to 9).

TERRITORY/HOME RANGE: Mean home range 0.25 acre (0.1 ha). Size of territory, if any, unknown.

FOOD HABITS: Succulent stems and leaves of grasses and forbs; forages on ground.

OTHER: Constructs underground burrows and builds grass nests under snow in winter. Does not hibernate. Population size fluctuates from year to year.

REFERENCES: Jenkins 1948, Anderson 1959, Ingles 1965, Negus *et al.* 1977.

California Vole

M067 *(Microtus californicus)*

STATUS: No official listed status. Widespread and common.

DISTRIBUTION/HABITAT: Found throughout most of California, from the Pacific Coast to the Sierra Nevada to an elevation of about 3940 ft (1200 m) in grassy areas.

SPECIAL HABITAT REQUIREMENTS: Grasses or sedges, or both.

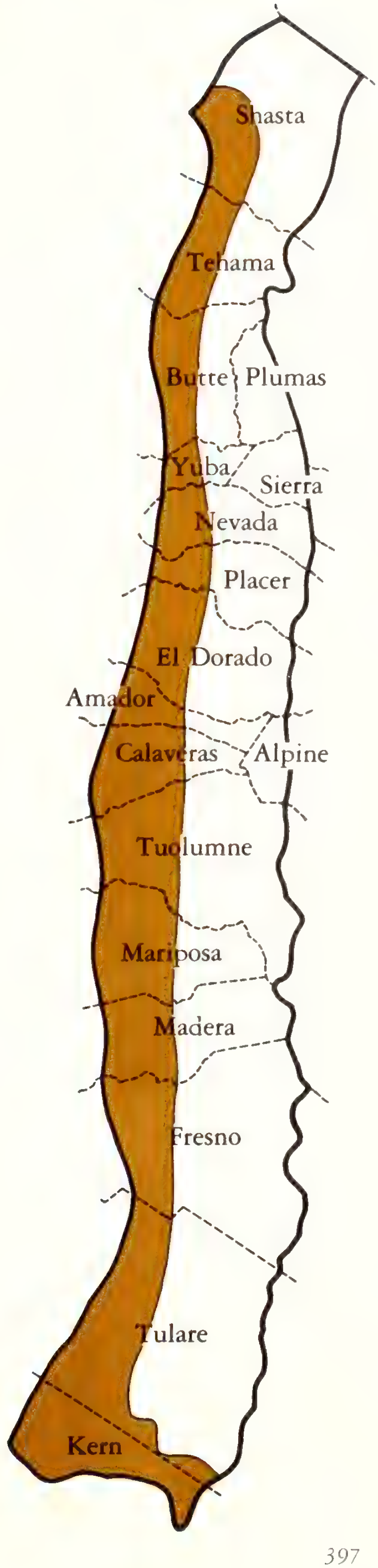
BREEDING: Breeds throughout year, reaching peaks whenever food and cover are abundant. Two to five litters each year. Mean litter size 4 (range of 1 to 9).

TERRITORY/HOME RANGE: Mean home range size in Monterey County is 0.37 acre (0.15 ha), ranging from 0.25 to 2.5 acres (0.1 to 1.0 ha) (Fisler 1962). Territorial behavior weak; size of defended area unknown.

FOOD HABITS: Eats primarily leafy portions of grasses, sedges, and herbs. Feeds on ground, clipping grasses and forbs to form network of runways leading from burrow.

OTHER: Presence of voles often may be confirmed by their runways. Runways constructed by clipping grass stems close to surface of ground. Populations cyclic for a period of 3 to 4 years, with peak population densities reaching 200/acre (500/ha). Does not hibernate.

REFERENCES: Fisler 1962, Batzli and Pitelka 1970, Krebs 1970, Gill 1977.



Long-tailed Vole

M068 (*Microtus longicaudus*)

STATUS: No official listed status. Widespread and common in suitable habitats.

DISTRIBUTION/HABITAT: Found throughout California at higher elevations in mixed-conifer, Jeffrey pine, red fir, and lodgepole pine forests.

SPECIAL HABITAT REQUIREMENTS: Grasses, sedges, or forbs.

BREEDING: Breeds from March to November; litter size 1 to 10 (mean of 5). Three or four litters per year. Nests usually in underground burrows.

TERRITORY/HOME RANGE: No information available on territorality. Home range size in El Dorado County varied from 0.25 to 9.9 acres (0.1 to 4 ha) (mean of 0.5 acre [0.2 ha]) (Jenkins 1948).

FOOD HABITS: Forages over ground (activities not confined to runways in summer.). Eats grasses, and grass-like plants, bulbs, and bark of small twigs. Constructs tunnels under snow.

OTHER: Does not hibernate. Populations relatively stable compared with those of other voles. Less restricted to runways and dense grasses than other *Microtus*.

REFERENCES: Jenkins 1948, Ingles 1965, Burt and Grossenheider 1976.

Muskrat

M069 *(Ondatra zibethicus)*

STATUS: No official listed status. Furbearer, protected by closed season during warmer months. Native to northeastern California, but introduced and range expanded in parts of the western Sierra Nevada.

DISTRIBUTION/HABITAT: Locally abundant along western edge of the Sierra Nevada, from Tulare County to Shasta County, with sparser populations at higher elevations. Riparian deciduous areas provide optimum habitat. Found in or near aquatic habitats.

SPECIAL HABITAT REQUIREMENTS: Permanent streams, ponds, or lakes; succulent grasses or sedges, or both.

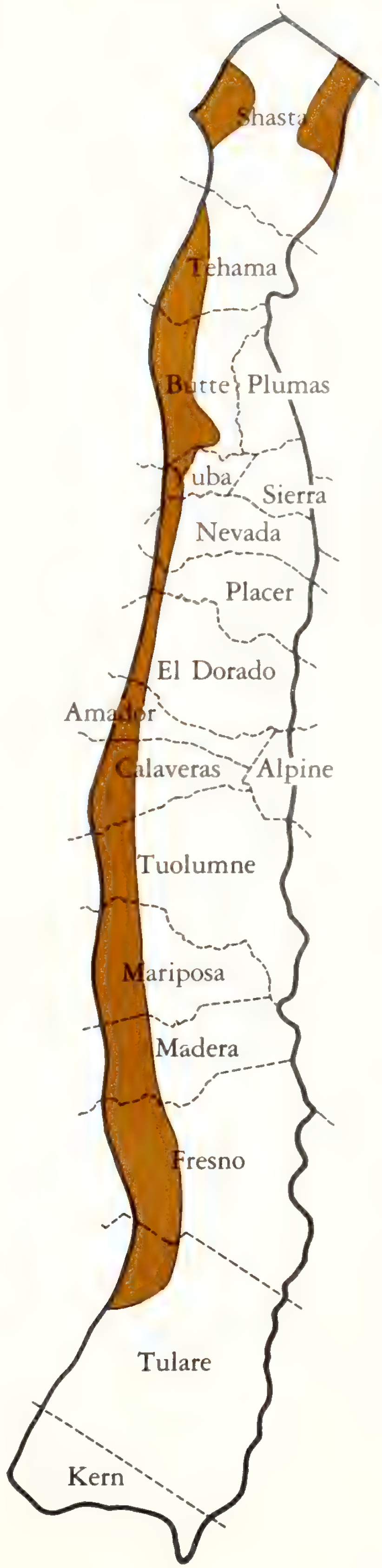
BREEDING: Breeds from March to August, with peak from April to June. Two or three litters per year. Young range from 1 to 11, with mean of 4 to 6. Burrows made in banks, and houses of cattails and tules, located in open water, used as nest sites.

TERRITORY/HOME RANGE: Usually sedentary; home ranges occasionally as large as 500 acres (200 ha). Defends nest area.

FOOD HABITS: Forages on banks of streams and in marshes for cattails and other aquatic plants.

OTHER: Active all year; nocturnal and diurnal.

REFERENCES: Grinnell *et al.* 1937, Errington 1963, Earhart 1969.



Western Jumping Mouse

M070 *(Zapus princeps)*

STATUS: No official listed status. Common locally.

DISTRIBUTION/HABITAT: Found throughout the Sierra Nevada from mixed-conifer zone upward in areas with herbaceous cover along edges of rivers, streams, lakes, meadows, and other wet areas. Found in all successional stages.

SPECIAL HABITAT REQUIREMENTS: Moist soil.

BREEDING: Breeds from June through July. Litter size from 2 to 7 (mean of 5). Nests placed in small depressions in ground and lined with grass; cover of grass or other vegetation placed over depression.

TERRITORY/HOME RANGE: Sedentary. Home range size averages 0.62 acre (0.25 ha) for females and 0.74 acre (0.3 ha) for males. Ranges may extend from 328 to 1300 ft. (100 to 400 m) along grassy banks and wet areas. Densities of 0.4/acre (1/ha) reported (Brown 1967, Myers 1969).

FOOD HABITS: Feeds on seeds of grasses and forbs. Harvests from ground.

OTHER: Hibernates from about September to May.

REFERENCES: Krutzsch 1954b; Brown 1967, 1970.

Porcupine

M071 *(Erethizon dorsatum)*

STATUS: No official listed status. Common over widespread range in the Sierra Nevada, although uncommon in some areas.

DISTRIBUTION/HABITAT: Found throughout the Sierra Nevada from digger pine-oak belt up to the lodgepole pine forests. Avoids chamise chaparrel and oak savannah areas; prefers medium- and old-age conifer stands of less than 70 percent crown closure

SPECIAL HABITAT REQUIREMENTS: Forests containing shrubs and grasses or herbs.

BREEDING: One litter per year born between March and June, with peak from April through May. One young (rarely 2) born among rocks, in caves, hollow logs, snags, or in the burrows of other animals.

TERRITORY/HOME RANGE: Ranges generally smallest in winter, averaging 12.4 acres (5.0 ha). Studies in New York and Minnesota, respectively, provide data on home range sizes (Shapiro 1949, Marshall *et al.* 1962).

FOOD HABITS: Feeds on herbs, shrubs, fruits, and buds when available in spring and summer, and twigs, leaves, and cambium layer of conifers, especially pines, throughout year. Forages on ground or in shrubs and trees. Clips leaves and twigs, and debarks trees.

OTHER: Known to be preyed upon by mountain lions, bobcats, fishers, and wolverines. Sometimes controlled because of damage to trees. Densities up to $26/mi^2$ ($10/km^2$). Does not hibernate.

REFERENCES: Taylor 1935, Curtis 1941, Woods 1973.

Coyote

M072 (*Canis latrans*)

STATUS: No official listed status. Common resident of the Sierra Nevada.

DISTRIBUTION/HABITAT: Widespread throughout the Sierra Nevada; found in almost every plant community and successional stage. Prefers habitat of grass-forb and shrub-seedling-sapling stages of all plant communities.

SPECIAL HABITAT REQUIREMENTS: Rock outcrops, caves, hollow stumps or logs, or deep, loose soil for den sites.

BREEDING: Females begin breeding during their second year and mate from February to May, with peak in April and May. Three to 15 young per litter (average 6 or 7); one litter per year. Gestation 63 days.

TERRITORY/HOME RANGE: In Sierra County, home ranges varied from 2470 to 24,700 acres (1000 to 10,000 ha) (Hawthorne 1972). Movements varied according to season.

FOOD HABITS: Eats mice, ground squirrels, gophers, rabbits, insects, carrion, fruits, and occasionally birds and deer fawns. Prey chased and captured in the open, or dug out of ground.

OTHER: May be active during day or night. Population densities know to vary from 0.02 to 1.2 individuals per 100 acres (40 ha). Two or more coyotes often cooperate while hunting.

REFERENCES: Gier 1968, Hawthorne 1972, Connolly and Longhurst 1975, Bekoff 1977.

Red Fox

M073 *(Vulpes vulpes)*

STATUS: No official listed status. Designated as fully protected furbearer by the California Department of Fish and Game. Populations highly vulnerable to disturbances, especially to overgrazing of alpine meadows.

DISTRIBUTION/HABITAT: Populations scattered in the Sierra Nevada; found primarily in upper elevation forests associated with the Sierra Nevada Crest. During summer, prefers mature Jeffrey pine, lodgepole pine, and red fir forests, interspersed with meadows. In winter, prefers mixed-conifer and ponderosa pine forests.

SPECIAL HABITAT REQUIREMENTS: Rock outcrops, hollow logs and stumps, or loose deep soil needed for den sites; forest openings.

BREEDING: Mates in late January and February; litters of 4 to 6 born in May and June. Dens found in rocky areas, talus, hollow stumps and logs and burrows.

TERRITORY/HOME RANGE: In the Midwest, home ranges were 321 to 5113 acres (130 to 2070 ha) (means of 494 to 1976 acres [200 to 800 ha]) (Ables 1975).

FOOD HABITS: Eats small rodents, squirrels, marmots, woodrats, pikas, rabbits, and insects. Also eats birds and berries. Hunts during day and night; stalks and pounces on prey.

OTHER: Separate population found in Sacramento Valley believed introduced from the East in 1880's. Four color phases recognized: black (rare), silver, red, and cross. *Vulpes* considered subgenus of *Canis* by some (Williams 1979).

REFERENCES: Grinnell *et al.* 1937, Ables 1975, Gray 1975, Schempf and White 1975.

Gray Fox

M074 *(Urocyon cinereoargenteus)*

STATUS: No official listed status. Furbearer, may be taken only during trapping season, with license. Rare to common in widespread range in the Sierra Nevada.

DISTRIBUTION/HABITAT: Found throughout lower foothill elevations; prefers chaparral and shrub-seedling-sapling stages of oak and digger pine woodlands; avoids dense and mature forests.

SPECIAL HABITAT REQUIREMENTS: Caves, hollow logs, snags, or rock crevices in talus for dens.

BREEDING: Breeds at 1 year of age and has one litter per year. Two to 7 young per litter are produced (average 3 or 4). Breeds from February to June, with peak from March to May. Dens found in rocky areas, crevices in cliffs, burrows, hollow logs, snags, and even buildings.

TERRITORY/HOME RANGE: Home ranges probably encompass up to 3.8 mi^2 (10 km^2), but average most likely between 0.2 to 1.2 mi^2 (0.5 to 3.0 km^2).

FOOD HABITS: Diet of mice, gophers, rabbits, woodrats, some birds, insects, fruits, and berries. Main hunting technique involves ambushing prey. Forages on ground and in shrubs; will climb trees.

OTHER: Crepuscular and nocturnal; active all year. Densities may reach 2.6 to 5 animals/mi^2 (1 or 2/km^2). In spring and summer, often associated in family aggregations. *Urocyon* considered conspecific with *Canis* by some (see Williams 1979).

REFERENCES: Grinnell *et at.* 1937, Lord 1961. Trapp and Hallberg 1975.

Black Bear

M075 *(Ursus americanus)*

STATUS: No official listed status. A big game species; common resident of the Sierra Nevada.

DISTRIBUTION/HABITAT: Widespread from digger pine-oak belt to alpine meadows. Prefers mature forests mixed with brushfields and meadows. Various habitats used, depending on availability of food (for example, mast crops and berries).

SPECIAL HABITAT REQUIREMENTS: Windfalls, excavated holes, or uprooted or hollow trees essential for den sites.

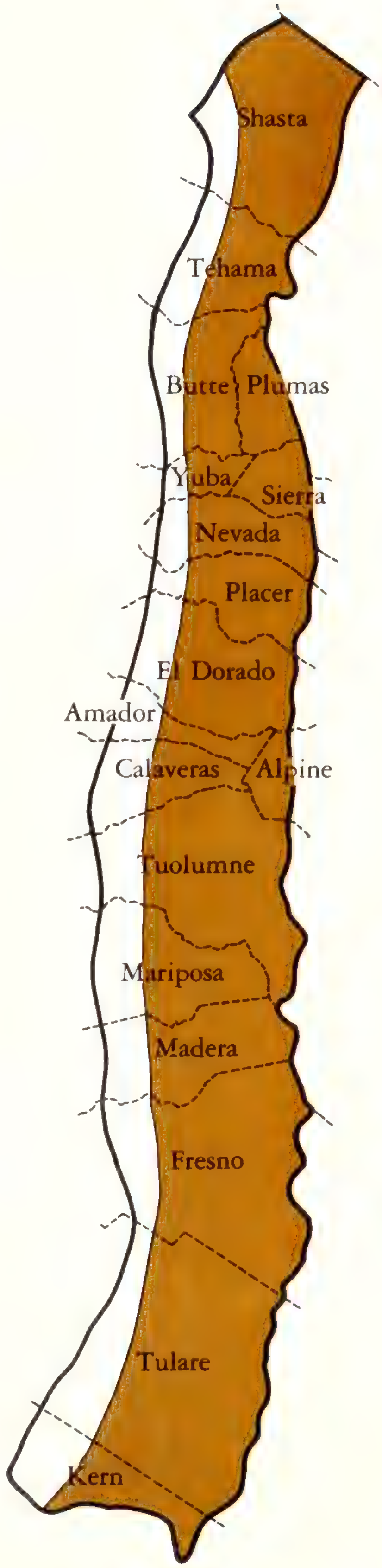
BREEDING: Mates in early summer; cubs born 7.5 months later in the winter den. Females first breed at 3 years of age and thereafter every second year. A 3-year-old female usually has 1 cub; twins and triplets common after that age.

TERRITORY/HOME RANGE: Home ranges of bears studied in Trinity County varied from 1235 to 6175 acres (500 to 2500 ha) (Piekielek and Burton 1975).

FOOD HABITS: Omnivorous and opportunistic. Diet of roots, fruits, nuts, grasses, insects, fish, small rodents, and carrion. Often tears apart rotting wood to locate insects and other animals; occasionally climbs trees in search of food.

OTHER: Den for much of winter; do not go into deep torpor. Can be aroused from dormancy at any time if sufficiently disturbed; may be active at any time of year. Suitable den sites may be a limiting factor affecting bear populations.

REFERENCES: Bray and Barnes 1967, Poelker and Hartwell 1973, Piekielek and Burton 1975.



Ringtail

M076 *(Bassariscus astutus)*

STATUS: No official listed status. A fully protected furbearer in California.

DISTRIBUTION/HABITAT: A permanent resident, widely distributed, varying in abundance from common to uncommon. Optimum habitats, provided crown closure less than 40 percent and special habitat requirements met: blue oak savannah, digger pine-oak, chaparral (with less than 50 percent shrub canopy cover), and riparian deciduous forests.

SPECIAL HABITAT REQUIREMENTS: Rock crevices or hollow trees or snags.

BREEDING: Young born in May and June (usual litter size 3 or 4). One litter per year. Rock piles, caves, abandoned burrows, holes in trees, woodrat nests, and occasionally human dwellings are den sites.

TERRITORY/HOME RANGE: Home ranges in Tuolumne County estimated to be 1250 to 1500 acres (500 to 600 ha) (Grinnell *et al.* 1937). A study in Texas found densities of 15.5/mi^2 (6/km^2) (Taylor 1954). May be colonial.

FOOD HABITS: Forages on ground, among rocks, and in trees. Rodents, especially mice and woodrats, are primary foods, but some birds, reptiles, insects, and fruits also eaten.

OTHER: Nocturnal; active all year. Usually not found more than 0.6 mile (1.0 km) from water.

REFERENCES: Grinnell *et al.* 1937, Taylor 1954, Ingles 1965.

Raccoon

M077 *(Procyon lotor)*

STATUS: No official listed status. Rare to common in different parts of widespread range. A trapping license required to take this furbearer.

DISTRIBUTION/HABITAT: Found in all types of habitats; generally associated with riparian or wetland areas in low to middle elevational zones.

SPECIAL HABITAT REQUIREMENTS: Suitable den sites (hollow trees, logs, snags) and water.

BREEDING: One litter per year; from 2 to 7 young (mean of 4). Young born between March and May. Gestation 63 days. Den sites in holes in trees, under rocks, in hollow logs, in ground burrows, or sometimes in thick vegetation.

TERRITORY/HOME RANGE: Does not seem to defend areas beyond immediate vicinity of den. Home ranges averaged about 250 acres (100 ha) in Ohio (Urban 1970).

FOOD HABITS: In spring, feeds mainly on animals, such as crayfish, fish, frogs, and small mammals; in summer and fall, also eats fruits, seeds, acorns, insects, and other invertebrates. Forages primarily on ground and in shallow water.

OTHER: Often common near human settlements, where densities can average 155 animals/mi^2 (60/km^2). Populations occasionally reach high densities and may need some control.

REFERENCES: Grinnell *et al.* 1937, Stuewer 1943, Ingles 1965.

Marten

M078 *(Martes americana)*

STATUS: No official listed status. A fully protected furbearer; listed as sensitive by the Forest Service's Region 5.

DISTRIBUTION/HABITAT: Widespread; common to rare in different areas. Optimum habitat provided by red fir and lodgepole pine forests with more than 40 percent crown closure and varying amounts of shrub understory. Good habitat in large tree stages of mixed-conifer and Jeffrey pine forests.

SPECIAL HABITAT REQUIREMENTS: Snags; talus.

BREEDING: Mates in summer; young born the next spring. Long gestation results from delayed implantation of embryos. One litter per year; mean litter size 3 (range 1 to 4). Tree or snag cavities, hollow stumps, or rocky slopes with caves are nest sites.

TERRITORY/HOME RANGE: Size of home ranges varied in Montana from 0.03 to 2 mi^2 (0.08 to 5.2 km^2), with a mean of 0.2 to 1.5 mi^2 (0.5 to 3.9 km^2) (Hawley and Newby 1957). Size of territory unknown.

FOOD HABITS: Searches for and captures tree squirrels, chipmunks , mice, rabbits, pikas, and occasionally birds. Also eats some fruits. Forages in trees, tree cavities, on rock slopes, and ground. Feeds in summer in meadows and forest openings.

OTHER: Active all year during day and night. May move to lower elevations in winter. Uses cavities in large trees or snags for shelter and nesting.

REFERENCES: Grinnell *et al.* 1937; de Vos 1952; Newberry 1973a; Schempf and White 1975, 1977.

Fisher

M079 *(Martes pennanti)*

STATUS: No official listed status. A fully protected furbearer in California; on the Forest Service's Region 5 sensitive list.

DISTRIBUTION/HABITAT: Uncommon to rare throughout range. Optimum habitat in large tree stages, regardless of crown closure, in red fir and lodgepole pine forests. Good habitat in large tree stages, with more than 70 percent crown closure, in ponderosa pine, mixed-conifer, and Jeffrey pine forests.

SPECIAL HABITAT REQUIREMENTS: Snags or hollow trees for nest sites.

BREEDING: Mates in summer; young born the next spring. Long gestation because of delayed implantation of embryos. Mean litter size 2, range from 1 to 5. One litter per year. Nests in tree holes, rock slides, hollow logs, and snags.

TERRITORY/HOME RANGE: Home ranges in Ontario, Canada estimated to average 10 mi^2 (26 km^2) (de Vos 1952). Size of territory unknown.

FOOD HABITS: Eats squirrels, porcupines, woodrats, mice, marmots, mountain beavers, rabbits, and some birds, insects, and berries. Searches for and pursues prey on the ground, in burrows, and in trees.

OTHER: Active all year during day and night. Cavities in large trees and snags used for shelter and nesting.

REFERENCES: Grinnell *et al.* 1937; de Vos 1952; Schempf and White 1975, 1977.

Ermine

M080 *(Mustela erminea)*

STATUS: No official listed status. A furbearer; capture requires trapping license; limited trapping season. Locally common, but rare in southern part of range.

DISTRIBUTION/HABITAT: Found at higher elevations in the middle and northern Sierra Nevada, in pine and fir forests. Prefers mature, dense timber for breeding and resting; meadows or other open areas for hunting.

SPECIAL HABITAT REQUIREMENTS: Ground litter, logs, stumps, or snags for den sites; forest openings.

BREEDING: Young born in April or May; average 4 young (as many as 13 reported). Dens located among tree roots, under rocks, in hollow logs and snags, and burrows.

TERRITORY/HOME RANGE: Home ranges varied from 25 to 37 acres (10 to 15 ha) (Burt and Grossenheider 1976).

FOOD HABITS: Major food is voles (*Microtus*); also eats mice, shrews, and chipmunks. Small but agile predator, searches for and pursues prey in logs, stumps, dead wood, tunnels, and burrows.

OTHER: Diurnal and nocturnal; active all year. Pelage white in winter. Populations often cyclic, patterned after prey's population cycles. Densities may reach 21/mi^2 (8/km^2) at high point of cycles.

REFERENCES: Hall 1951, Ingles 1965.

Long-tailed Weasel

M081 *(Mustela frenata)*

STATUS: No official listed status. Fairly common over most of the western Sierra Nevada. A furbearer; protected by trapping season.

DISTRIBUTION/HABITAT: Found throughout all habitats from foothill grasslands to alpine meadows. Prefers meadows and other open areas, and young sapling stages of timber.

SPECIAL HABITAT REQUIREMENTS: Suitable den sites (ground cover, logs, stumps, snags, or burrows); forest openings.

BREEDING: Mates in July or August; gestation long (179 days), with young born in April or May. Four to 8 young (average 6) born in burrows under roots, rocks, logs, in hollow trunks of trees and snags, and sometimes in burrows of other animals.

TERRITORY/HOME RANGE: May range over areas from 25 to 125 acres (10 to 50 ha), but average size of home range is 25 to 49 acres (10 to 20 ha) (Quick 1951, Burt and Grossenheider 1976).

FOOD HABITS: Major predator of voles and other mice. Also eats chipmunks, woodrats, gophers, some birds and insects, and vegetation. Obtains prey by searching in logs, stumps, dead wood, tunnels, and burrows.

OTHER: Diurnal and nocturnal; active throughout year. Molts to a white pelage in winter at higher elevations. In good habitat, average densities may be $2.6/mi^2$ ($1/km^2$), and may range as high as $18/mi^2$ ($7/km^2$) in favorable habitats.

REFERENCES: Grinnell *et al.* 1937, Quick 1951, Ingles 1965.

Mink

M082 *(Mustela vison)*

STATUS: No official listed status. Rather uncommon, but widespread. A furbearer, may be taken only during trapping season.

DISTRIBUTION/HABITAT: A variety of habitats, but primarily riparian and wetland.

SPECIAL HABITAT REQUIREMENTS: Permanent source of water, and suitable burrowing sites.

BREEDING: Single litter of 2 to 10 (mean of 5) born between February and May. Most births in April. Gestation from 38 to 85 days, depending on time of mating. Age at first breeding usually 1 year. Den sites include burrows, hollow logs, tree stumps, and rock crevices.

TERRITORY/HOME RANGE: May range over areas up to 1240 acres (500 ha), but home range sizes in Montana varied between 49 and 185 acres (20 and 75 ha) (Mitchell 1961).

FOOD HABITS: Pursues fishes, frogs, crayfish, mice, muskrats, rabbits, and some birds in shallow water and on land, near water.

OTHER: Generally nocturnal; active all year. Relatively tolerant of human activities. Densities may reach 23/mi² (9/km²).

REFERENCES: Grinnell *et al.* 1937, Mitchell 1961, Schempf and White 1974.

Wolverine

M083 *(Gulo gulo)*

STATUS: Listed as Rare by the State of California; a fully protected furbearer. Historically, never present in large numbers; numbers thought to be increasing in California.

DISTRIBUTION/HABITAT: Distribution scattered, mostly near timberline. Optimum habitat in large tree stages with moderate to dense canopy cover in red fir and lodgepole pine forests, and in alpine meadows.

SPECIAL HABITAT REQUIREMENTS: Low human disturbance; rocky areas, caves, logs, or snags as den sites.

BREEDING: Mates in summer; 1 to 4 young (mean of 3) born the next spring. Long gestation because of delayed implantation of embryos. One litter per year. Excavates burrows under shelving rock or in logs, caves, or snags.

TERRITORY/HOME RANGE: In Montana, distances between locations of 3.1 to 8.1 miles (5 to 13 km) with daily movements of up to 20 miles (32 km) reported (Hornocker and Hash 1976).

FOOD HABITS: A solitary hunter; forages on ground, in trees, burrows, and rock piles for carrion or live prey. Captures prey by digging animal out of its burrow, by pursuit and capture, or by ambush. Prey include marmots, gophers, squirrels, rats, mice, birds, insects, and occasionally ungulates. Fruits also eaten.

OTHER: Active by day and night all year. Often found above timberline. Scant data on home range, movements, and habitat requirements.

REFERENCES: Grinnell *et al.* 1937; Hornocker and Hash 1976; Schempf and White 1975, 1977.

Badger

M084 *(Taxidea taxus)*

STATUS: No official listed status. A furbearer; protected by a closed season. Uncommon, but widely distributed throughout the western Sierra Nevada.

DISTRIBUTION/HABITAT: Grass-forb stages of all habitats except riparian deciduous are optimum.

SPECIAL HABITAT REQUIREMENTS: Open areas with friable soils.

BREEDING: From 1 to 5 young (mean litter size 2) born between February and May. One litter per year. Deep, friable soil for burrow excavation and a dependable supply of rodents.

TERRITORY/HOME RANGE: In Minnesota, home range sizes varied from 100 to 500 acres (40 to 200 ha) (Sargeant and Warner 1972). Territory size unknown; densities of 0.4 to 3.4/mi^2 (0.15 to 1.30/km^2) recorded in northeastern Colorado (Flinders and Hansen 1975).

FOOD HABITS: Digs out or chases ground squirrels, gophers, rats, mice, and chipmunks from burrows. Also eats ground nesting birds and their eggs, lizards, and snakes.

OTHER: Diurnal and nocturnal; spends much time underground.

REFERENCES: Grinnell *et al.* 1937, Sargeant and Warner 1972, Long 1973.

Western Spotted Skunk

M085 *(Spilogale gracilis)*

STATUS: No official listed status. Common locally, but not frequently seen.

DISTRIBUTION/HABITAT: Found in several habitats from annual grasslands through ponderosa pine zone. Prefers chaparral and shrub-seedling-sapling stage of pine-oak woodlands.

SPECIAL HABITAT REQUIREMENTS: Rock outcrops, ground burrows, hollow logs, stumps, snags, or brush piles for den sites.

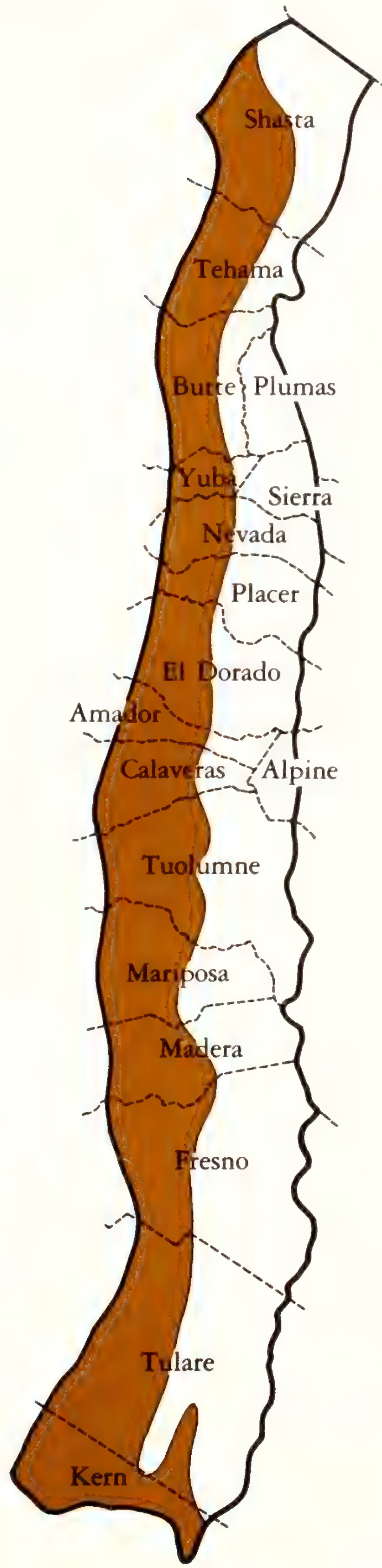
BREEDING: One litter per year; 4 to 7 young (mean of 6), born in May and June. Dens in any sheltering cavity in rock outcrops, burrows, hollow logs, stumps and snags, and brush piles. Gestation as long as 120 days.

TERRITORY/HOME RANGE: Territoriality not known, but home ranges may vary from 25 to 160 acres (10 to 65 ha) (Burt and Grossenheider 1976).

FOOD HABITS: Eats mostly insects and small rodents, also some reptiles, amphibians, birds, eggs, and plant matter. Food obtained by searching, digging, and climbing. Areas searched include ground surface, stumps, snags, and logs.

OTHER: Usually nocturnal and crepuscular. Does not hibernate, but may den up for several days at a time in winter: den sites, therefore, a key component of habitat. Densities may reach 13/mi^2 (5/km^2).

REFERENCES: Grinnell *et al.* 1937, Crabb 1948, Haley 1975.



Striped Skunk

M086 (*Mephitis mephitis*)

STATUS: No official listed status. Usually common within its range.

DISTRIBUTION/HABITAT: Prefers shrubby areas in annual grasslands, chaparral, and pine-oak woodlands of the Sierra Nevada. Prefers younger successional stages in forests, but may be found in all stages and canopy covers.

SPECIAL HABITAT REQUIREMENTS: Suitable den sites (rock piles, logs, snags, and burrows).

BREEDING: One litter per year; 2 to 10 young (mean of 6), born between April and June (peak in May). Dens located mostly in rock piles; old burrows, hollow logs, stumps, and snags also used.

TERRITORY/HOME RANGE: Home ranges from 74 to 2000 acres (30 to 800 ha), but in Illinois averaged 1000 acres (400 ha) (Storm 1972). Extent of territoriality unknown.

FOOD HABITS: Feeds mainly on large insects and small rodents, but eats some carrion, birds, eggs, and plant matter. Food obtained by digging in soil and searching on ground surface and in hollow stumps, snags, and logs.

OTHER: Chiefly nocturnal and crepuscular. Does not hibernate, but may den up for several days at a time, especially in winter. Densities may reach 259/mi^2 (100/km^2).

REFERENCES: Grinnell *et al.* 1937, Verts 1967, Storm 1972.

River Otter

M087 *(Lutra canadensis)*

STATUS: No official listed status. Usually fairly rare, but individuals may be locally common. Fully protected; may not be hunted.

DISTRIBUTION/HABITAT: Patchy distribution in the Sierra Nevada. Found only near permanent water. Foothill zones preferred to higher regions.

SPECIAL HABITAT REQUIREMENTS: Large streams, lakes, or rivers essential.

BREEDING: Sexually mature at 2 years; males reach peak at from 5 to 7 years. Gestation period as long as 1 year because of delayed implantation of embryos. Single litter of 1 to 5 cubs (mean of 2) born in April or May. Dens located in burrows dug by other animals, cavities among roots of trees, hollow logs, or thickets of vegetation.

TERRITORY/HOME RANGE: May travel up to 15 miles (25 km) following stream or lake edges. Deposits scent (sign posting) to mark territories.

FOOD HABITS: Fish, crayfish, amphibians, aquatic invertebrates, and some mammals. Some trout taken, but slower fishes (for example, sculpins and squawfish) preferred. Most food acquired by pursuit in the water and on nearby banks.

OTHER: Diurnal and nocturnal; active all year. Social animals; may remain in family groups for 8 months.

REFERENCES: Grinnell *et al.* 1937, Liers 1951, Newberry 1973b, Haley 1975, Kirk 1975.

Mountain Lion

M088 (*Felis concolor*)

STATUS: No official listed status. Legislative moratorium on hunting this species in effect in California. Estimated population level in California between 1000 and 2500 individuals.

DISTRIBUTION/HABITAT: Widespread, with greatest densities in the central and southern Sierra Nevada. Found throughout all habitat types and successional stages.

SPECIAL HABITAT REQUIREMENTS: Suitable den sites in rock crevices or caves; deer for food.

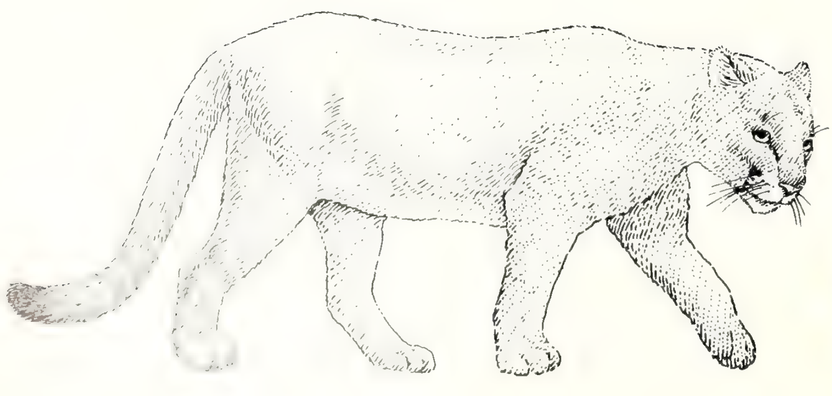
BREEDING: Breeds at any time of the year, with peak in April. Litter size from 1 to 5 (mean of 2). One litter every 2 years. A den required to raise young.

TERRITORY/HOME RANGE: Home ranges may overlap considerably; vary in size from 5 to 20 mi^2 (13 to 52 km^2) for females, and 25 to 96 mi^2 (65 to 250 km^2) for males in the Salmon River drainage, Idaho (Hornocker 1970).

FOOD HABITS: Deer are primary food; also porcupines, rabbits, and rodents. Captures prey by stalking or ambush in areas of rocky or brushy cover.

OTHER: Active all year during day and night. Usually closely associated with deer.

REFERENCES: Hornocker 1970, Sitton and Wallen 1976, Koford 1977.



Bobcat

M089 *(Felis rufus)*

STATUS: No official listed status. A furbearer, may be taken only in designated season.

DISTRIBUTION/HABITAT: Widespread with densities from locally common to uncommon. Found in nearly all habitats and successional stages. Shrub-seedling-sapling stages of woodlands and forests, and all stages of chaparral are optimum habitats.

SPECIAL HABITAT REQUIREMENTS: Rocky areas, caves, or logs.

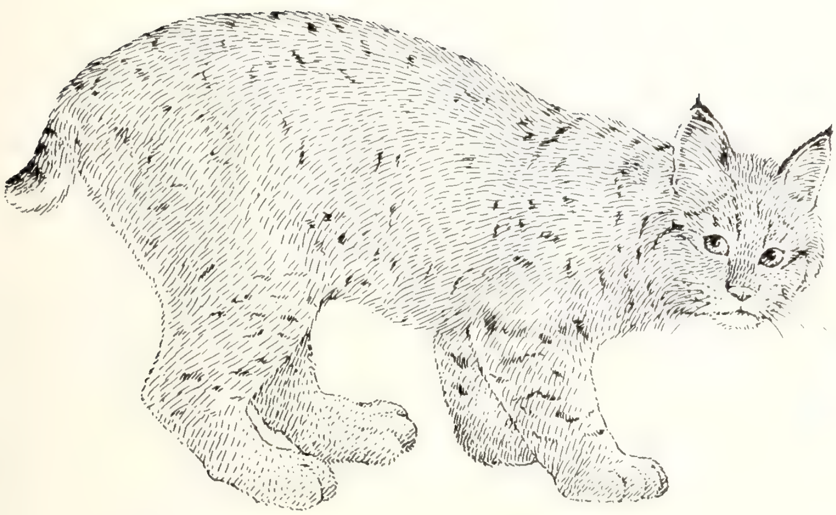
BREEDING: Breeds from January to June, with peak from February to May. Litter size from 1 to 6 (mean of 3); one litter per year. A den site in small caves, crevices, under logs, or dense brush required for raising young.

TERRITORY/HOME RANGE: Home range varies in size, depending on prey availability. In Idaho, home ranges were from 1 mi^2 (2.6 km^2) to 41 mi^2 (105 km^2) (Bailey 1974).

FOOD HABITS: Stalks or ambushes prey on ground in brushy and rocky areas. Feeds on rats, mice, squirrels, and other rodents, a few birds, reptiles, and invertebrates.

OTHER: Active all year, during both night and day.

REFERENCES: Young 1958, Provost *et al.* 1973, Bailey 1974.



Wild Horse

M090 *(Equus caballus)*

STATUS: No official listed status. Species fully protected. Only one small population in the Sierra Nevada.

DISTRIBUTION/HABITAT: Found in grassland, chaparral, and oak woodland habitats in Tehama County in the western Sierra Nevada.

SPECIAL HABITAT REQUIREMENTS: Needs grasses and water.

BREEDING: Groups composed of harems—1 dominant stallion, 1 or 2 immature stallions, 1 to 12 adult mares with yearlings and foals, and 1 to 3 immature mares. One foal born to a mare annually, between March and July; majority of births in May. Mares give birth in seclusion, usually during nighttime.

TERRITORY/HOME RANGE: Space not defended; but stallion defends harem. In Wyoming, home ranges varied from 740 to 7910 acres (300 to 3200 ha) (mean of 3710 acres [1500 ha]) (Feist and McCullough 1975).

FOOD HABITS: Grasses, forbs, and shrubs are major foods.

OTHER: Grouped in harems, or in bachelor herds of 1 to 8 or more stallions.

REFERENCES: Feist and McCullough 1975, 1976; Zarn *et al.* 1977.

Wild Pig

M091 *(Sus scrofa)*

STATUS: No official listed status. Introduced from Europe; a big game animal in California.

DISTRIBUTION/HABITAT: Distribution spotty in the Sierra Nevada. Found at lower elevations in annual grasslands and oak woodlands, but mostly in denser stands of chaparral and digger pine-oak forests with canopy closures of at least 50 percent.

SPECIAL HABITAT REQUIREMENTS: Water and shrubs.

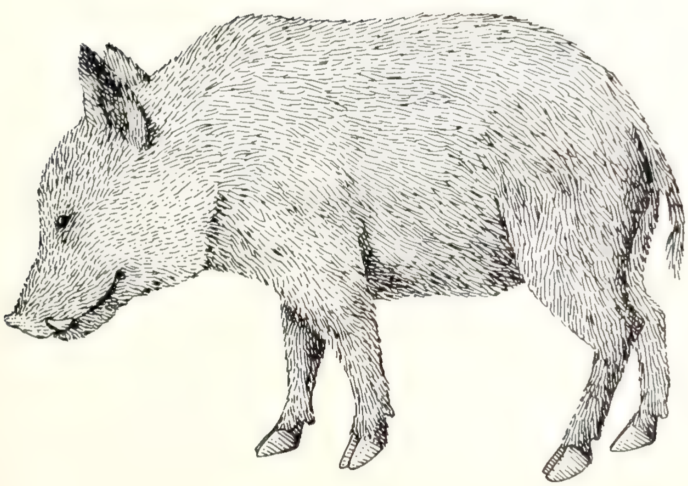
BREEDING: One or two litters per year, up to 11 per litter (mean of 4). Main breeding season from October through June; some may breed at any time of year. Gestation lasts 4 months.

TERRITORY/HOME RANGE: Sedentary; stays with food and water supplies until diminished. Travels from 0.6 to 3 miles (1 to 5 km), and occasionally up to 12 miles (20 km) over several months; not territorial (Pine and Gerdes 1973).

FOOD HABITS: Acorns, berries, fruit, forbs, grasses, cultivated grains, bulbs, roots, earthworms, snakes, lizards, and carrion. Obtains food by rooting in soil, in rotted logs, and by more conventional means.

OTHER: Because of food habits, can be agricultural pests. Densities vary from at least 1.3 to $4/mi^2$ (0.5 to $1.5/km^2$).

REFERENCES: California Department of Fish and Game 1970, Pine and Gerdes 1973, Nelson and Hooper 1976, Barrett 1978.



Wapiti

M092 (*Cervus elaphus*)

STATUS: No official listed status. Currently protected from hunting, except for occasional hunts by special permit.

DISTRIBUTION/HABITAT: Only population within the western Sierra Nevada introduced into Shasta County. Prefers meadows and grasslands with surrounding cover for shelter.

SPECIAL HABITAT REQUIREMENTS: Dense cover for shelter; grasses.

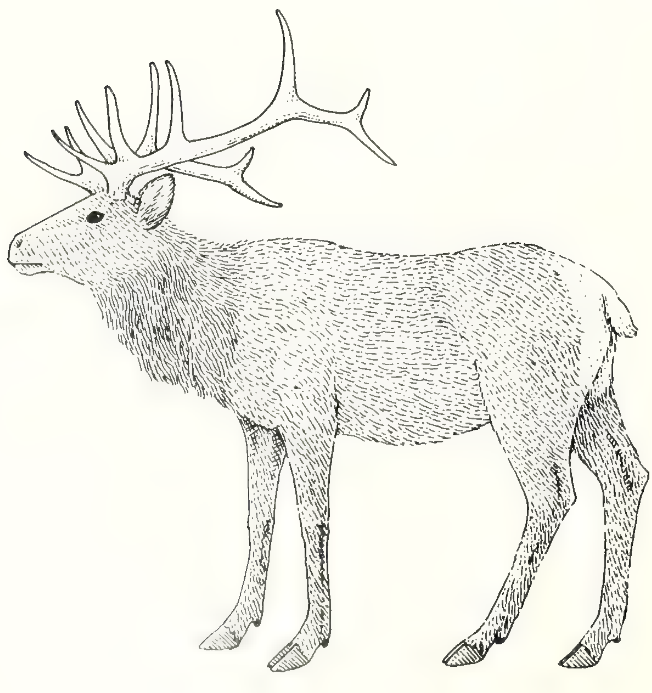
BREEDING: Breeds from April to June, with peak in May. Usually only 1 calf, but twins not uncommon. Cows must be at least 2 years old to give birth, usually in a secluded area with good cover. Gestation 255 days.

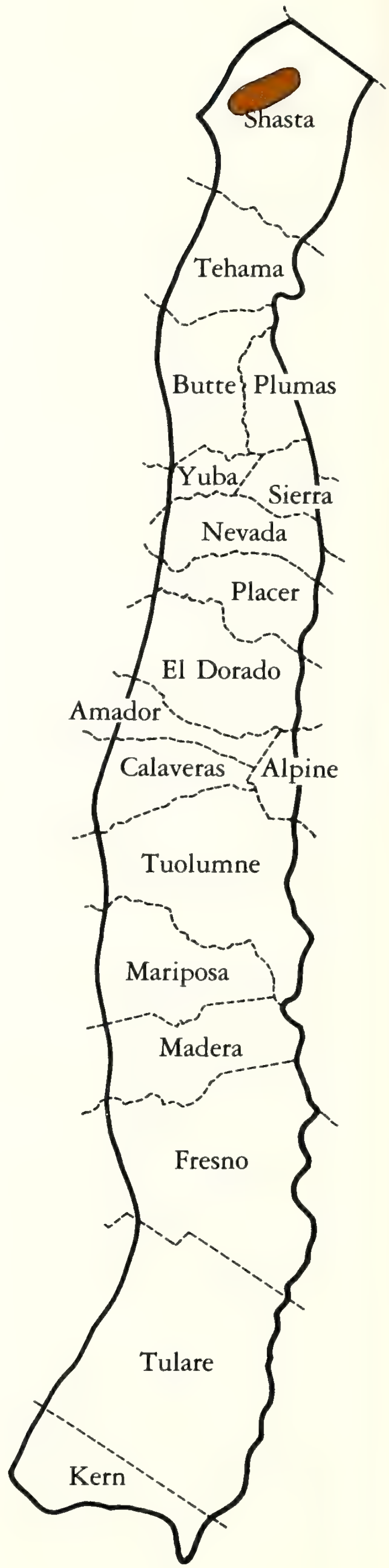
TERRITORY/HOME RANGE: Not territorial, but home range up to 20 mi^2 (50 km^2) in the Rocky Mountians (Hieb 1977).

FOOD HABITS: Diet primarily grasses, forbs, browse, and some mast.

OTHER: Population of 50 elk introduced into Shasta County in 1913; now numbers 350.

REFERENCES: Murie 1951, Mackie 1970, Hieb 1977.





Mule Deer

M093 *(Odocoileus hemionus)*

STATUS: No official listed status. A big game species.

DISTRIBUTION/HABITAT: Widespread and common; numbers may be declining. Shrub-seedling-sapling stages of most habitats best.

SPECIAL HABITAT REQUIREMENTS: Trees-shrubs for cover on winter range.

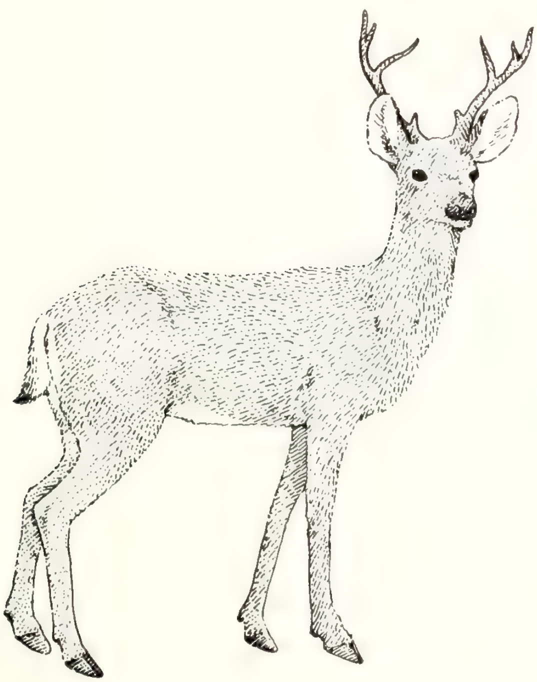
BREEDING: Mates from mid-September through December, with peak in October and November. Usually 1 or 2 (rarely 3) fawns born in May, June, or early July (average 1.5 fawns from each doe). Scattered areas of dense cover near meadows and glades, with nearby lush feed, as fawning sites.

TERRITORY/HOME RANGE: Typical home range covered 0.4 to 1.1 mi^2 (1 to 3 km^2), but varied from 0.2 to 1.9 mi^2 (0.5 to 5.0 km^2) in Lake County (Taber and Dasmann 1958). Statewide, densities of 18 to 60/mi^2 (7 to 23/km^2) typical, with range from 5 to 104/mi^2 (2 to 40/km^2) (Longhurst *et al.* 1952). Not territorial.

FOOD HABITS: Tender new growth of various shrubs—ceanothus, cherry, mountain mahogany, many forbs, and some grasses.

OTHER: Yearlings breed when habitat conditions excellent. Most herds migratory, follow definite routes between summer and winter ranges. May be active at any hour of day.

REFERENCES: Longhurst *et al.* 1952, Taylor 1956, Taber and Dasmann 1958.



Mountain Sheep

M094 *(Ovis canadensis)*

STATUS: Designated Rare by the California Department of Fish and Game. Few isolated populations in the Sierra Nevada; numbers may be decreasing.

DISTRIBUTION/HABITAT: Southern end of the Sierra Nevada in perennial range and alpine meadows in summer; east side of the Sierra Nevada in winter.

SPECIAL HABITAT REQUIREMENTS: Rocky areas adjacent to meadows to protect young lambs; minimal disturbance from humans.

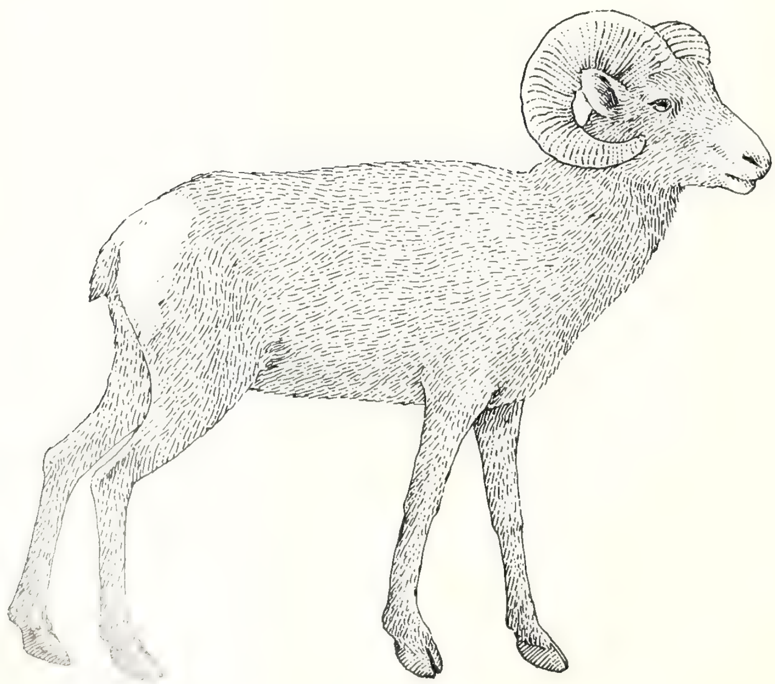
BREEDING: One or two lambs born in May or June in broken, rugged cliffs where protected from predators. Gestation 180 days.

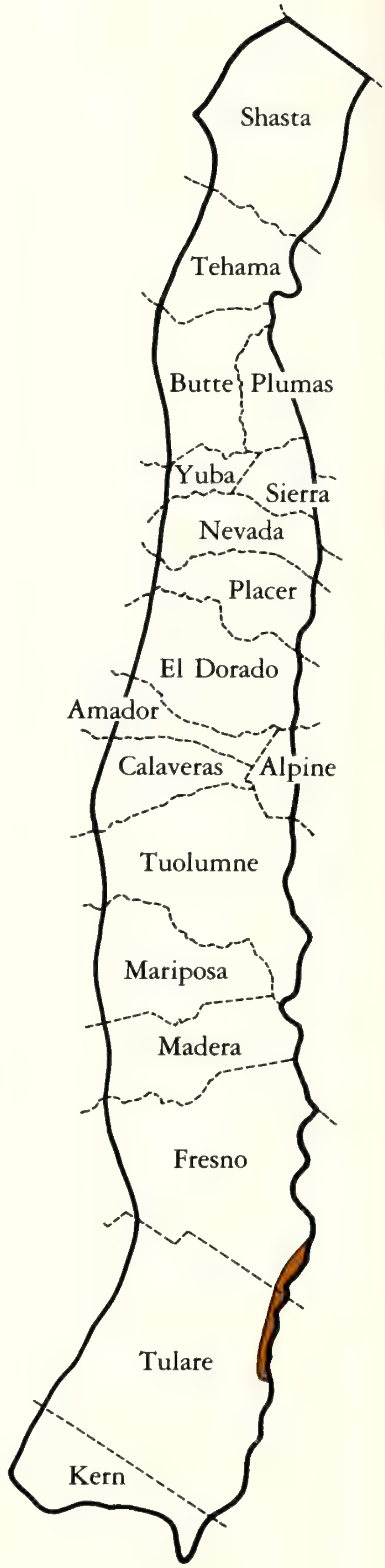
TERRITORY/HOME RANGE: Not territorial; herds may range over 60 to 155 mi^2 (150 to 400 km^2) (Dunaway 1970).

FOOD HABITS: Eats alpine shrubs and forbs in summer; shrubs and perennial grasses in winter.

OTHER: Good quality range critical.

REFERENCES: Packard 1946, McCullough and Schneegas 1966, Dunaway 1970, Geist 1971, Hicks and Elder 1979.





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**Pacific Southwest
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a user's guide to Probit Or LOgit analysis

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POLO:

a user's guide to Probit Or LOgit analysis

Jacqueline L. Robertson Robert M. Russell N. E. Savin

CONTENTS

POLO (Probit Or LOgit) is a computer program specifically developed to analyze data obtained from insecticide bioassays. Prior to its development, other computer programs by Daum (1970), Daum and Killcreas (1966), and Walton[1] were used for that purpose. After using these programs extensively, we concluded that they were neither sufficiently accurate for our needs, nor did they produce the output we desired.

The statistical procedures incorporated into POLO, its documentation, and examples of its application are described in articles by Robertson and others (1978a,b), Russell and others (1977), Russell and Robertson (1979), and Savin and others (1977). Copies of these articles may be obtained upon request to:

Director
Pacific Southwest Forest and Range Experiment Station
P.O. Box 245
Berkeley, California 94701
Attention: Publication Distribution

The POLO program is also available upon request. A magnetic tape with format instructions should be sent to the above address, attention: Computer Services Librarian. The program is currently operational on the Univac 1100 Series, but can be modified for other large scientific computers.

This guide was prepared to assist users of the POLO program. Statistical features of the program, suggestions for the design of experiments that provide data for analysis, and data input and output formats are described in detail.

1. STATISTICAL FEATURES

POLO performs the computations for probit or logit analysis with grouped data. For a discussion of these methods, see, for example, the text by D. J. Finney (1971). In contrast to previous programs, the computational procedure has been completely freed from dependence on traditional manual methods and is entirely computer-oriented.

The statistical basis for POLO is a binary quantal response model with only one independent variable in addition to the constant term. Consider subjects placed in one of T possible experimental settings, where each setting requires one of two possible responses from the subject. For example, in a bioassay in which insects are treated with one of T doses of a chemical insecticide, the possible responses are

[1]Walton, Gerald S. Unpublished program for probit analysis. Copy of program on file at the Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Berkeley, California.

dead or alive. There is a measured characteristic of the test subjects for each experimental setting. We denote a numerical function of the measured characteristic for the t-th setting by z_t. In the bioassay example, the measured characteristic is the dose; the numerical function z_t may be the dose, the logarithm of the dose, or some other function of the dose.

The model analyzed is $P_t = F(\alpha + \beta z_t)$, where F is a cumulative distribution function (CDF) mapping the points on the real line into the unit interval. For the probit model

$$P_t = F(\alpha + \beta z_t) = \Phi(\alpha + \beta z_t)$$

where Φ is the standard normal CDF. For the logit model

$$P_t = F(\alpha + \beta z_t) = 1/[1 + e^{-(\alpha + \beta_t)}]$$

Both models are estimated by the method of maximum likelihood.

Beyond the traditional computations, POLO tests hypotheses involving two or more regression lines. When several chemical preparations are compared, a probit or logit regression line is calculated independently for each preparation. Two hypotheses are tested next. The first hypothesis is that all regression lines are equal, that is, that all have the same intercept and the same slope. The second hypothesis is that all lines are parallel, that is, all have the same slope. Both hypotheses are tested by means of the likelihood ratio test.

The standard normal and logistic CDF's are quite close to one another except in the extreme tails. Therefore, similar results are obtained with either model unless data comes from the extreme tails of the distribution. For theoretical and empirical reasons for using these functions, other sources should be consulted (Berkson 1951, Cox 1966, Finney 1971).

2. ASPECTS OF BIOASSAY DESIGN

POLO output is only as good as the data input. Program output is the basis for valid statistical inference about the probit or logit model, provided that an appropriate experimental design has been employed in the data collection process. In the following discussion, we consider aspects of experimental design of insecticide bioassays. With suitable generalization, the same considerations pertain to many other binary quantal response bioassays, such as those with drugs or plant growth regulators.

2.1 Selection of Test Subjects

The population of test subjects should be carefully defined before the bioassay is performed. Once a population—for example, larvae in a particular developmental stage—has been defined, the test subjects should be randomly selected in order to eliminate bias in the experimental results.

To ensure randomization, it is advisable to use a random number table or some other randomization device. Suppose, for example, that an insecticide is to be applied to last stage lepidopterous larvae within a particular weight range. The population, therefore, is composed of all insects in the last instar whose weight lies within the designated limits. Consider 75 rearing containers holding appropriate test subjects. One randomization procedure consists of numbering the containers from 1 to 75. For one day's test, five containers will provide sufficient test subjects; these five are selected by choosing the containers corresponding to the first five digits of a list of random numbers from 1 to 75. For the next day's test, containers matching the next five digits of the random number list may be used. This procedure may be repeated until all of the insects needed have been selected, assuming that insects in the original 75 containers remain within the weight limits.

During a given day's test, insects are frequently grouped with others for treatment. For example, a bioassay may be conducted with larvae held in petri dishes in groups of 10. Nine dose levels will be applied to the larvae held in 18 dishes. One way to randomize dosage assignments would be to number the petri dishes as they are filled. Using a random number table, the investigator may then assign the dishes corresponding to the first two digits of a random number table to dose level A, the second two to dose level B, and so on.

These randomization procedures work well, given a relatively unlimited supply of test subjects such as that provided by a continuous laboratory culture. When wild populations are tested, some modifications of randomization procedures may be necessary. For example, natural units such as cones may be numbered, then selected at random for assignment to bioassays with each of a group of insecticides. These randomization techniques are not the only ones which an investigator may follow; however, we have found them useful in our routine bioassays. Instructions for using random number tables are available in statistical textbooks (Goldstein 1964, Snedecor and Cochran 1967).

2.2 Sample Size

The maximum likelihood estimates and likelihood ratio tests used in POLO have desirable large

sample properties. There appears to be no firm guideline regarding the sample size (that is, number of test subjects) which must be used for these desirable properties to hold. Typically, we have used 300 to 500 insects for each bioassay of a particular chemical performed with test subjects selected from a laboratory colony.

When insects are obtained from field collections, their numbers are frequently limited. Even when the number of test subjects is not limited, the time available for a bioassay may be a limiting factor. In general, we have found that treatment of more insects with fewer compounds is preferable to treatment of fewer insects with more compounds. This procedure tends to maximize the number of test subjects treated with a single chemical.

2.3 Dosage Selection

A preliminary dose-fixing experiment is a useful step in the selection of the test dosages to be applied in a bioassay. In this procedure, a small number of test subjects is used to test the effects of a wide range of dosages. Suppose, for example, that insecticide A is to be tested for the first time on a target insect species. We suggest that a logarithmic series of dilutions from 0.001 to 10.0 mg/ml be tested, with each concentration applied to 10 insects at the usual volume or rate. The complete series of dosages in this experiment would be 0 (controls treated with solvent only), 0.001, 0.01, 0.10, 1.0, 10.0 (mg/ml). The resultant percentage mortalities might be: control—0; 0.001—0; 0.01—0; 0.10—30; 1.0—100; 10.0—100. These data would serve as a guide for dosage selection for the main bioassay.

More precise estimates of the probit and logit lines are obtained when some dosages are placed in the tails of the tolerance distribution and some are placed in the middle, rather than clustering all dosages in the middle. When only five dosages are used, 95 percent confidence limits for the lethal dosages cannot be computed about 25 percent of the time due to the high values of g (see p. 9). Therefore, we recommend that eight or more dosages be used to estimate any regression by means of POLO. From the results of the dose-fixing experiment described above, we would use the following dosages in the first replication of the main experiment (mg/ml): 0.05, 0.07, 0.10, 0.20, 0.30, 0.50, 0.70, and 1.0.

After the first replication, a further adjustment of dosages can be made. Suppose the results of the first replication of our hypothetical bioassay were (percent mortality): control—0; 0.05—0; 0.07—5; 0.10—20; 0.20—35; 0.30—43; 0.50—52; 0.70—80; 1.0—90. For the second replication, it would be wise to omit the 0.05 mg/ml dosage and add one of 2.0 mg/ml. Ideally, a range of mortalities from about 5 percent to about 95 percent should result from treatment with dosages finally selected.

2.4 Control Groups

A control group should be included in any bioassay. In our insecticide bioassay example, the control is considered to be a dose level of 0 mg/ml. The rationale for control groups is self-evident. Without them, an investigator can never be certain that lethal effects are wholly attributable to the insecticide being tested. The solvent or an impurity in the solvent may have been toxic to the test subjects.

Excess test subjects should not be used as the control group. The controls must represent a random sample selected from the population by the same criteria and procedures used to assign test subjects to any other dose group. Preferably, each test chemical should have its own control; an alternative, but less desirable, design uses a combined control consisting of all control groups from all chemicals tested in a particular experiment. Using either type of control data, POLO will calculate a theoretical control response ("natural response") for each chemical on an individual basis. The program will also calculate response lines without controls; in this instance, the program assumes that control mortality is zero. Unless the investigator has reason to asssume that control mortality is in fact zero, this option is not recommended.

POLO calculates a theoretical response rate of untreated test subjects—the "natural response." It should be emphasized that natural response and control group mortality are not the same. Natural response is a theoretical rate based on the pattern of responses exhibited at all dose levels. The zero and lowest dosages, however, carry more weight in the calculations. Control group mortality is the response rate actually observed in the control group; random variation may cause it to differ somewhat from the theoretical rate.

2.5 Replication

A bioassay should be replicated (that is, repeated several times) in order to randomize effects related to laboratory procedure, such as worker or day effects. Suppose that chemical A is to be tested on a population of insects from a laboratory colony. The supply of test subjects is plentiful, so that a minimum of three replications can be performed.

Obvious differences between the results of one replication and another suggest that laboratory procedures, such as formulation or application tech-

nique, should be investigated. In our hypothetical bioassay, the first replication of applications of chemical A killed 5 to 95 percent of the test subjects, but all test subjects were killed by all dosages in the second replication. The purpose of the next replication should then be to trace whether a procedural error had occurred in either of the two preceding replications.

3. DATA INPUT FORMAT

3.1 Starter Cards

Every POLO run starts with five cards which call the program from a tape (*fig. 1*):

```
1 @RUN,8   WU0000,000-0000,,2,200
2 @ASG,T   X.,T,U 3444
3 @COPY,G  X.
4 @FREE    X.
5 @XQT     POLO
```

Figure 1

Cards 2-5 must be punched as shown. Some modification of card 1 is possible. Columns 9-23 identify a particular work unit and account number which can be changed to identify the particular user. Column 26 is the time limit, 28-30 the page limit. Time and page limits can be changed to suit the user's particular needs. In most cases, 2 minutes and 200 pages far exceed what is necessary for an analysis.

The fifth starter card can be modified slightly for very restricted use (*fig. 2*). In some of the bioassays for which POLO was designed, dosages must be multiplied by 10 to appear in the conventional units usually reported. Specifically, dosages in topical application bioassays of insecticides are applied at the rate of μg/100 mg body weight; they are reported in units of μg/g body weight. Substitution of a card reading

```
@XQT,T   POLO
```

Figure 2

for starter card 5 multiplies lethal dosages reported in the last summary printed by the program by 10. The dosages printed in the body of the output are not converted. This input format option is available for special circumstances only.

By using the starter format (*fig. 1*), units reported in the summary and body of POLO output will be the same as units in the data input.

3.2 Header Cards

Each group of data sets starts with a header card with an equal sign (=) punched in column 1. Anything desired can be punched on the rest of the card. The computer merely prints everything on the header card, so any information useful for identifying the data sets should be entered (*fig. 3*):

```
1 =TA-CO6-S-1-78.PYRETHRINS.DOSAGE EXPRESSD
2 =IN PPM.F77-ND.WT.60-90 MG.
```

Figure 3

There can be any number of header cards introducing the data sets.

3.3 Preparation Cards

Each data set is composed of the dose-response data. Each separate group (insecticide, generation, treatment method) is called a preparation and is identified by an asterisk (*) in column 1. The name of the preparation should start in column 2. The computer retains only the first eight characters and uses them to label the printout. If a name or group title exceeds eight characters, it is wise to abbreviate the titles so that separate groups are identified. For example, carbaryl has been tested in two different formulations, S.4.0 and S.L. If the following preparation cards (*fig. 4*) were used, the computer would identify each group with the same label (CARBARYL):

```
1 *CARBARYL S.4.0
2 *CARBARYL S.L.
```

Figure 4

However, preparation cards using abbreviations would identify each preparation clearly (*fig. 5*):

```
1 *C-S40
2 *C-SL
```

Figure 5

3.4 Dosage-Response Cards

One card per dose group should be punched. POLO will analyze one to 300 dose groups for each preparation. Each dose-response card contains three fields, punched in order. The first field is dose, the second is number of subjects, the third is number responding (for example, dead). The number in each field need not appear in particular columns. Only one or more spaces need separate the fields. If each preparation has its own control group, it should be entered as a dose-group with dose level

zero. The order of the dosage-response cards does not matter (*figs. 6* and *7*). Analyses of both data sets in these examples would be identical.

```
=TA-CO6-S-1-75 F54-ND 7  DAYS S15126
*S15126
  Ø 4Ø   2
  1 1Ø   3
  2 9Ø 55
  5 9Ø 72
  7 91 78
 1Ø 1ØØ 89
 2Ø 89 85
```

gure 6

```
=TA-CO6-S-1-75 F54-ND 7  DAYS S15126
*S15126
1 1Ø 3
7  91 78
 2Ø 89 85
 Ø 4Ø 2
 2   9Ø 55
5 9Ø 72
1Ø 1ØØ 89
```

ure 7

No firm rationale exists for definition of dose groups. In *figures 6* and *7*, data for four replications (dose-fixing and main experiment) of the experiment have been combined. Another, perhaps preferable, procedure is to list data for each replication separately (*figure 8*). This procedure tends to minimize test statistics such as HET (*p. 9*) and *g* (*p. 9*) by increasing the number of degrees of freedom used in the linear regression calculations.

```
=TA-CO6-S-1-75 F54-ND 7  DAYS S15126
*S15126
  Ø 1Ø   8
  1 1Ø   3
 1Ø 1Ø   9
  Ø 1Ø   2
  2 3Ø  18
  5 3Ø  24
  7 3Ø  26
 1Ø 3Ø  3Ø
 2Ø 3Ø  28
  Ø 1Ø   Ø
  2 3Ø  18
  5 3Ø  22
  7 3Ø  24
 1Ø 3Ø  29
 2Ø 3Ø  28
  Ø 1Ø   2
  2 3Ø  19
  5 3Ø  26
  7 3Ø  28
 1Ø 3Ø  3Ø
 2Ø 29  29
```

gure 8

3.5 Control Group Cards

As noted above, individual control groups for each preparation are entered as a dose-group with a dose level of zero. POLO will calculate probit or logit lines without control groups; however, *if one preparation has a control group, all other preparations must also have a control.* We recommend an experimental design in which each test group or preparation has its own control group. If, however, the experimental design is such that a single control group applies to all of the preparations, the joint control group should be entered as if it were an additional preparation with one dose group. The preparation card is *NATURAL and the dose group card contains the dosage (0), the number of subjects, and the number responding (*fig. 9*):

```
*NATURAL
 Ø  129 21
```

Figure 9

3.6 Metameter

If doses are not to be converted to logarithms by POLO, a D-card should be entered following the dose-response data (*fig. 10*):

```
D 1
```

Figure 10

The D-card has a D punched in column 1, followed by one or more spaces, then the number 1. Suppose, for example, that dosages were converted to logarithms during the summarization of dosage-response data. Dosages might then be listed on the dosage-response cards as follows (*fig. 11*):

```
=CHORISTONEURA SPECIES.RESMETHRIN
*V-72
   Ø     4Ø    Ø
-1.523  68    13
-1.3Ø1  77    26
-1.155  76    38
-1.ØØØ  79    55
-Ø.699  79    69
D 1
```

Figure 11

Further conversion of the dosages would result in logarithms of logarithms; therefore, the D-card should be used to ensure that the dosages would be used as is. This option is called the "arithmetic" metameter.

3.7 Command Cards

If command cards are not used, POLO's standard calculations will be performed. These consist of calculations of individual probit lines for each preparation, the likelihood ratio test for equality among all preparations listed behind each header card, and the likelihood ratio test of parallelism of the preparations. Other options can be selected by use of command cards.

3.7.1 C-Card

The first command card is a C-card, which contains a C in column 1 and up to three numbers following. The C and the numbers must be separated from one another by blank spaces. If only a C is punched in column 1, the card is equivalent to a C followed by three zeroes. This is, in turn, equivalent to no card at all, and results in the standard output. Thus, the standard output will result from:

- No command card
- A card with C in column 1 (*fig. 12*):

	1	2	3	4	5	6	7	8	9	10
1	C									

Figure 12

- A card with C in column 1 and three zeroes, with the zeroes separated from the C and each other by a space (*fig. 13*):

	1	2	3	4	5	6	7	8	9	10
1	C		ø		ø		ø			

Figure 13

If a one is substituted for the first zero, logit analysis will be performed (*fig. 14*):

	1	2	3	4	5	6	7	8	9	10
1	C		1		ø		ø			

Figure 14

If a one is substituted for the second zero, the natural response parameter will not be estimated by maximum likelihood (ML). In *figure 15*, logit analysis without estimation of natural response is to be performed; in *figure 16*, probit analysis without estimation of natural response is commanded:

	1	2	3	4	5	6	7	8	9	10
1	C		1		1		ø			

Figure 15

3	C		ø		1		ø			

Figure 16

Finally, the substitution of a one for the last zero affects the interpretation of the next command card, the P-card (see sec. 3.7.3). If the last number is zero, the entries on the P-card are merely starting values to aid the computer in its search for the optimum, or maximum likelihood, value. If a one is entered, the values on the P-card are to be considered final and no search will be undertaken by the computer. The figures below illustrate all possible combinations:

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
1	C		1		ø		ø								(A)
2	C		1		1		ø								(B)
3	C		1		1		1								(C)
4	C		1		ø		1								(D)
5	C		ø		ø		ø								(E)
6	C		ø		1		ø								(F)
7	C		ø		ø		1								(G)
8	C		ø		1		1								(H)

Figure 17

Figure 17A specifies logit analysis, with estimation of natural response and a computer search for maximum likelihood values of other parameters. *Figure 17B* specifies logit analysis without estimation of natural response, but with a computer search for ML values of other parameters. *Figure 17C* commands logit analysis without estimation of natural response; specified values of the other parameters are designated by the P-card to follow. Finally, *figure 17D* commands logit analysis, estimation of natural response, but values of other parameters will be specified by the P-card.

The command cards for probit analysis are shown in *figures 17E to H. Figure 17E* commands probit analysis, estimation of natural response, and ML search for other parameters (*STANDARD OPTION*). *Figure 17F* designates probit analysis without estimation of natural response, but with ML search for other parameters. *Figure 17G* commands probit analysis, estimation of natural reponse, but values of the other parameters will be specified by the P-card. Finally, *figure 17H* commands probit analysis without ML estimation of natural response, and with values of other parameters specified by the P-card.

3.7.2 L-Card

The second command card, the L-card, specifies the percentages for which lethal dosages (LD's), will be calculated. These percentages are integers from 1 to 99. As many as 12 percent levels may be listed. At least one space should separate the numbers (*fig. 18*):

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	
1	L			5		1	ø		1	5		3	5		5	ø		6	ø		6	5		7	5		8	ø		9	ø		9	5		9

Figure 18

The L-card in *figure 18* will result in printing of LD_5, $_{10}$, $_{15}$, $_{35}$, $_{50}$, $_{60}$, $_{65}$, $_{75}$, $_{80}$, $_{90}$, $_{95}$ and $_{99}$ in the output. Omitting the L-card results in printing of the standard LD's—LD_{10}, LD_{50}, LD_{90}.

3.7.3 P-Card

The last command card, the P-card, should be used only under unusual circumstances. It allows the user to specify starting values of the parameters. In most instances, these might be estimates of ML values to help POLO maximize the likelihood func-

tion. For this use, the C-card must have a zero punched as the last of the three numbers.

When a one is punched as the third entry on the C-card, the values on the P-card will be used as fixed parameters; the program will not search for a supposedly more optimal set.

3.7.4 Cautions

If any command card is present, the C-card must also be present even if it is empty. Those command cards present must be in the order C, L, P.

A group of command cards produces a single type of analysis of the data. These may be followed by other command cards which will produce a different analysis of the same data.

Following the command cards, another data set may be entered. This would consist of the header card(s) distinguished by an equal sign (=) in column 1, dose-reponse data, and, perhaps, command cards. To the computer, this is an entirely new batch of data bearing no relationship to those preceding or any following.

3.7.5 Options: An Example

In the following example of the use of command cards for multiple analyses of the same data, two preparations have been tested (*fig. 19*). Natural response will be estimated as a parameter. The data first will be analyzed using probits; the analysis will then be repeated using logits. There is a joint control group valid for both preparations. The only LD to be printed is the LD_{50}.

```
  ESTIMATION OF NATURAL RESPONSE RATE.
  SEE FINNEY,PROBIT ANALYSIS,1971,PAGE
  132.
 STANDARD
  6.19  125  125
  4.58  117  115
  3.1   127  114
  1.49   51   49
  0.371 132   37
 TEST
 4.8  128  142
 0.0  127  126
  80  128  115
  20  126   58
 NATURAL
    0   129   21
   0  0  0
   50
   1  0  0
   58
```

Figure 19

3.8 Sample Input for Standard Probit Analysis

Figure 20 illustrates a typical input for probit analysis. All of the card groups—starter, header, preparation, and dosage-response—are illustrated.

```
 1 @RUN,8  WU0000,000-0000,,2,200
 2 @ASG,T  X.,T,U13444
 3 @COPY,G X.                              A
 4 @FREE   X.
 5 @XQT    POLO
 6 =CHORISTONEURA SPECIES.TROPICAL
 7 =APPLICATION.RESMETHRIN                 B
 8 •V-72                                   C-1
 9    0  40   0
10 0.03  68   13
11 0.05  77   26                           D-1
12 0.07  76   38
13 0.10  79   55
14 0.20  79   69
15 •L-74                                   C-2
16    0 359   7
17 0.1   70   22
18 0.2   49   27                           D-2
19 0.3   50   38
20 0.5   50   48
21 •C-74                                   C-3
22    0 30    0
23 0.02 48   12
24 0.03 50   15
25 0.05 50   31                            D-3
26 0.07 48   31
27 0.10 59   52
28
```

Figure 20

The starter cards are in group A, the header cards are in group B. Card C-1 is the preparation card for the first data set; card C-2, the preparation for the second set; card C-3 the preparation card for the third set. The preparation data sets themselves are contained on card sets D-1, D-2, and D-3. To obtain standard logit analyses, rather than probit analyses, of the same data sets, a C-card specifying the logit transformation (*fig. 14*) must follow each data set (D-1, D-2, and D-3).

The output from this set of sample data is discussed in detail in section 5. Briefly, an analysis of each data set, the likelihood ratio test for equality of the three sets, and the likelihood ratio test for parallelism will be printed. If the user is interested in pair comparisons, each pair must run separately behind a separate header card (*fig. 21*). For large numbers of pair comparisons (for example, those for all possible combinations of two from a group of 15 preparations) a computer storage system may be used.

```
=COMPARISON OF V-72 AND L-74
*V-72
   Ø 4Ø Ø
Ø.Ø3 68 13
Ø.Ø5 77 26
Ø.Ø7 76 38
Ø.1Ø 79 55
Ø.2Ø 79 69
*L-74
   Ø 359  7
 Ø.1 7Ø 22
 Ø.2 49 27
 Ø.3 5Ø 38
 Ø.5 5Ø 48
=COMPARISON OF V-72 AND C-74
*V-72
   Ø 4Ø Ø
Ø.Ø3 68 13
Ø.Ø5 77 26
Ø.Ø7 76 38
Ø.1Ø 79 55
Ø.2Ø 79 69
*C-74
  Ø   3Ø  Ø
Ø.Ø2  48 12
Ø.Ø3  5Ø 15
Ø.Ø5  5Ø 31
Ø.Ø7  48 31
Ø.1Ø  59 52
```

Figure 21

The elements (preparations) can then be recalled as needed for the various pair comparisons.

4. DATA OUTPUT FORMAT

In this section, the format of data output from POLO (*fig. 22*), will be described in detail. A sample output, resulting from the input shown in *figure 20*, is presented in its entirety. Probit analysis is performed; the format for logit analysis is identical.

4.1 Data Printback

All cards for preparations following each header card are printed back prior to the statistical analysis (*fig. 22A*). After the analysis for one group is completed, the next group following the next header card is printed, then analyzed. This printback feature provides an opportunity for rechecking the accuracy of the data input.

4.2 Metameter Listing

The next section of the data output (*fig. 22B*) lists each preparation, dose, dose-metameter transformation, subjects, responses, and decimal proportion of responses. The number or preparations and number of dose-response cards follows the metameter listing.

4.3 Analysis Message

Following the metameter list, POLO prints a message specifying the analysis conducted. (*fig. 22C*). The user is told which transformation will be used for the analysis, whether natural response is a parameter, and whether the program will estimate parameters by maximum likelihood.

4.4 Individual Preparation Printout

Terminology in the printouts for individual preparations is derived from Finney (1971). When the user is unsure of statistical meanings or derivations of terminology, Finney's text should be consulted. Use of likelihood ratio tests in the context of probit and logit analyses is discussed by Savin and others (1977).

The top of each page repeats the first header card (line 1, secs. D1, D2, and D3).[2] Next, the constraints of the analysis are stated together with the preparation title (line 2, secs. D1, D2, D3). For individual preparations, intercepts and slopes are always unconstrained. The analyses are simply regressions of each dose metameter on response, with correction for natural response where appropriate. Note that the position of each preparation in the group is specified by the numeral immediately preceding the preparation title in line 2. In the third line of the individual analyses (line 3, secs. D1, D2, D3), POLO states whether or not it will estimate natural response as a parameter. In sections D1 and D3, no response was observed in either control group; it follows, therefore, that the program will operate by "not estimating natural response." In section D2, on the other hand, the program will be "estimating natural response" because mortality was observed in the control.

In the fourth line of the printout, the logarithm of the maximum value of the likelihood function for each preparation is presented (line 4, secs. D1, D2, D3). In the next section (lines 5-7, secs. D1, D3; lines 5-8, sec. D2), values of the intercept (α, labelled with the preparation title), slope, and natural response (where appropriate) are listed in the column called "parameter." The standard errors and t-ratios

[2]For purposes of easier reference, section and line divisions are cited on the following pages which relate specifically to the computer printout in *figure 22*.

(parameter value ÷ standard error) of each parameter are listed in the succeeding columns.

The variance-covariance matrix of the parameters is listed next (lines 8-11, secs. D1, D3; lines 9-13, sec. D2), followed by the chi-squared goodness-of-fit test (lines 12-18, secs. D1, D3; lines 15-20, sec. D2) The chi-square value, degrees of freedom, and heterogeneity factor (which equals the chi-square divided by the degrees of freedom) follow (line 19, secs. D1, D3; line 21, sec. D2). When the heterogeneity factor exceeds 1.00, the user is cautioned by a warning (lines 22-24, sec. D2; lines 20-22, sec. D3). The program suggests that a plot of the data be consulted, since the model fits the data poorly. Although random variation (that usually termed "experimental error") may account for a large chi-square (and heterogeneity), a plot of the data may reveal systematic variation from linear regression. In this eventuality, use of a different mathematical function may be more appropriate for analyzing the data. In most cases, we have found that variation in insecticide bioassays cannot be classified as systematic; nevertheless, the user has been warned of a problem with the data and is free to decide what, if anything, to do about it.

The "index of significance for potency estimation" (line 20, sec. D1; line 25, sec. D2; line 23, sec. D3) is the statistic g which is used for calculation of confidence limits at three probability levels—90, 95, and 99. If, at any of these levels, g exceeds 1.00, the values of the mean may lie outside the limits; for very large values of g, the confidence limits run from $-\infty$ to $+\infty$ (Finney 1971). As a safety feature, POLO calculates confidence limits only when g is less than 0.5 at either the 90, 95, or 99 percent probability levels. A warning about g is printed (lines 26-27, sec. D2; lines 24-25, sec. D3) when g at any of the three probability levels is over 0.5. Should this occur, a statement (line 28, sec. D2; line 26, sec. D3) of the maximum value of g which the program will accept is made. Note that the value of g is less than 0.5 at all three probability levels in section D1; no warning statement appears, and 90, 95 and 99 percent confidence limits have been calculated (lines 21-25, last 6 columns). In sections D2 and D3, however, g exceeds 0.5 at the 99 percent probability level; the user is given the g warning and only 90 and 95 percent confidence limits are calculated (last four columns each of lines 29-33, sec. D2 and lines 27-31, sec. D3).

Calculated effective doses (lethal doses or lethal concentrations, depending on the test technique) are the final portion of each printout (lines 21-25, sec. D1; lines 29-33, sec. D2; lines 27-31, sec. D3). In the first column, the dose level of percent effect is labelled. The standard option lists LD_{10}, LD_{50}, and LD_{90}. In the next column, the preparation name is reprinted. The column labelled DOSE lists the calculated dosage required for the specified percent effect. In *figure 22*, the LD_{10}'s, LD_{50}'s and LD_{90}'s are:

Preparation	LD_{50}	LD_{50}	LD_{90}
V-72	0.02159	0.06852	0.21753
L-74	0.05913	0.16239	0.44596
C-74	0.01329	0.04139	0.12892

4.5 Likelihood Ratio Test of Equality

Section E is the portion of the POLO printout for the likelihood ratio test of equality of the three individual preparations shown in sections D1, D2, and D3. The header card message is printed first (sec. E, line 1), followed by a description of the statistical hypothesis tested (line 2). The test of equality constrains the slopes and intercepts to be the same. With these constraints, the lines would be the same. Natural response is not estimated in determining the composite line (3) for comparison.

Lines 4-11 contain the statistics for the composite lines and are analogous to those for the individual preparations (lines 4-11, secs. D1, D3; lines 4-13, sec. D2). The most important calculation listed is the logarithm of the maximum value of the likelihood function for the composite line (line 4, sec. E).

The next section presents the likelihood ratio test for equality itself (lines 12-14, sec. E). To determine whether the lines are equal, the program is "testing the hypothesis that slopes and intercepts are the same" (line 12, sec. E). The negative of twice the value of the difference of the sum of the likelihood functions of the individual preparations and the likelihood function of the composite line is distributed as a chi-square (line 13, sec. E). The degrees of freedom (d.f.) (line 13, sec. E) equals the number of parameters for each line (=2), multiplied by the number of lines (in this example, 3) minus the number of parameters constrained in the composite line (slope + intercept, =2). Thus, d.f. equals $(2 \times 3) -2$, or 4 in the present example. POLO then calculates the probability corresponding to the chi-square with the proper degrees of freedom (line 13, sec. E). If the probability is greater than 0.05, the hypothesis is accepted; if the probability is less than 0.05, the hypothesis is rejected. In this example, the hypothesis is rejected (line 14, sec. E).

In the remaining portion of the printout, the same information previously presented for individual lines (preparations)—the chi-squared goodness-of-fit statistic, heterogeneity, g, effective dosages, their limits, and appropriate warnings—is listed for the composite line (lines 15-43, sec. E). The user need not be concerned with large values of chi-squared, heterogeneity factors, or g values which commonly appear for composite lines. If lines are grossly unequal, these statistics will become quite large.

4.6 Likelihood Ratio Test of Parallelism

The likelihood ratio test for parallelism (sec. F) follows the test for equality. Once again, the header title is printed (line 1, sec. F). The statistical hypothesis to be tested follows. For the test of parallelism, the slopes of the individual preparation lines are constrained to be the same (line 2, sec. F). Natural response is not estimated (line 3, sec. F).

The logarithm of the likelihood function for the composite line generated when the slopes of the preparations are constrained to be the same is calculated next (line 4, sec. F). The intercepts for the individual preparations with slopes constrained (lines 6-8, sec. F) and the slope of the composite line (line 9, sec. F), standard errors of the parameters and t-ratios for each line are printed. The variance-covariance matrix is also listed (lines 10-15, sec. F).

The likelihood ratio test for parallelism (lines 16-18, sec. F) is presented in the same format described for the test of equality. Degrees of freedom, (d.f) for the test equals the number of preparations (three) times the number of parameters constrained (one:the slope), minus the number of constrained parameters in the composite line (one:the slope). In this example, d.f. = $(3 \times 1) - 1 = 2$. As in the test for equality, the hypothesis is accepted when the tail probability is greater than 0.05. In the present example, the hypothesis is accepted.

The statistics for the chi-squared goodness-of-fit test of the combined line and the calculation of *g* are shown in lines 19-36, section F. These precede the calculations of effective doses and confidence limits for the individual preparations (lines 37-50, sec. F) assuming the same slope as the composite line. Finally, the potency of each preparation relative to the first preparation in the group (lines 51-55, sec. F) is calculated according to the procedures of Finney (1971, p. 100-124).

4.7 Summaries

The first summary printed by POLO (*fig. 22*) is a guide to the body of the analysis and a synopsis of pertinent information. The header card title is first printed (line 1, sec. G). Then, key statistics for each preparation are listed (lines 2-13, sec. G). The first line lists the preparation title, number of subjects treated, number of controls, and the page number on which the detailed analysis for the preparation is to be found (lines 2, 8, 14, sec. G). In the next line, the log of the likelihood function, slope ± standard error, and natural response ± standard error are listed (lines 3, 9, 15, sec. G). Heterogeneity and the value of *g* at the 95 percent level follow (lines 4, 10, 16, sec. G). The next three lines give LD_{10}, LD_{50}, and LD_{90} values with their respective 95 percent confidence limits (lines 5-7, 11-13, 17-19, sec. G). The last two groups summarize the likelihood ratio tests for equality and parallelism (line 20-26, 27-33, sec. G). The statistics for each composite line with the appropriate constraints are printed as they were for individual preparations. If the value of *g* exceeds 0.5 at the 95 percent level, no list of LD values will appear in the summary. The user should refer to the analysis for possible reasons.

The second summary (sec. H) was designed for immediate assessment of results and photo reduction. The columns are:

Abbreviation	Data presented
PREP	Preparation
N	Number of test subjects
NC	Number of controls
C, SE	Estimated natural response ± its standard error
BETA, SE	Slope ± its standard error
LD_{50}, 95% limits	Calculated lethal dose for 50 percent effect and 95 percent confidence limits of that dose
LD_{90}, 95% limits	Calculated lethal dose for 90 percent effect and 95 percent confidence limits of that dose
HET	Heterogeneity factor (chi squared ÷ degrees of freedom)
G	*g* at the 95 percent probability level
LOG L	Logarithm of the maximum value of the likelihood function
HYP	OK indicates whether either hypothesis tested (equality or parallelism) is accepted (p> 0.05)

4.8 Error Messages

Error messages clearly indicate mistakes in the data input:

Message	Reason
The data on this card seems to be out of order.	The number responding on a dosage-response card is greater than the number of test subjects. The usual reason is transposing of the numbers when either writing the data forms or punching the cards.
If one preparation has a control group, all preparations must have a control group.	Self-explanatory
EUREKA	Your data are so outlandish that no analysis can be performed. Try again.

gure 22—Data output from POLO is shown in printouts.

Page 1

A

```
CARD: =CHORISTONEURA SPECIES. RESMETHRIN
CARD: *V-72
CARD:     0  40  0
CARD: 0.03  68  13
CARD: 0.05  77   26
CARD: 0.07  76   38
CARD: 0.10  79   55
CARD: 0.20  79   69
CARD: *L-74
CARD:    0  359  7
CARD: 0.10  70   22
CARD: 0.2   49   27
CARD: 0.3   50   38
CARD: 0.5   50   48
CARD: *C-74
CARD:    0   30  0
CARD: 0.02   48   12
CARD: 0.03   50   15
CARD: 0.05   50   31
CARD: 0.07   48   31
CARD: 0.10   59   52
```

B

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PREPARATION       DOSE        LOG-DOSE       SUBJECTS  RESPONSES  RESP/SUBJ
V-72             .00000        .000000         40.         0.        .000
                 .03000      -1.522879         68.        13.        .191
                 .05000      -1.301030         77.        26.        .338
                 .07000      -1.154902         76.        38.        .500
                 .10000      -1.000000         79.        55.        .696
                 .20000       -.698970         79.        69.        .873
L-74             .00000        .000000        359.         7.        .019
                 .10000      -1.000000         70.        22.        .314
                 .20000       -.698970         49.        27.        .551
                 .30000       -.522879         50.        38.        .760
                 .50000       -.301030         50.        48.        .960
C-74             .00000        .000000         30.         0.        .000
                 .02000      -1.698970         48.        12.        .250
                 .03000      -1.522879         50.        15.        .300
                 .05000      -1.301030         50.        31.        .620
                 .07000      -1.154902         48.        31.        .646
                 .10000      -1.000000         59.        52.        .881

NUMBER OF PREPARATIONS: 3        NUMBER OF DOSE GROUPS: 14
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C

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THE PROBIT TRANSFORMATION IS TO BE USED
NATURAL RESPONSE IS A PARAMETER
THE PARAMETERS ARE TO BE ESTIMATED BY MAXIMIZING THE LIKELIHOOD FUNCTION
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Page 2

D1

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1   CHORISTONEURA SPECIES. RESMETHRIN

2   INTERCEPTS AND SLOPES UNCONSTRAINED.  PREPARATION IS (1) V-72
3   NOT ESTIMATING NATURAL RESPONSE

4   MAXIMUM LOG-LIKELIHOOD   -214.00397

5                PARAMETER        STANDARD ERROR      T RATIO
6   V-72         2.9739201         .32912820         9.0357497
7   SLOPE        2.5545776         .28119539         9.0847064

8   VARIANCE-COVARIANCE MATRIX
9                  V-72             SLOPE
10    V-72         .1083254         .9042676-01
11    SLOPE        .9042676-01      .7907085-01

12  CHI-SQUARED GOODNESS OF FIT TEST

13  PREPARATION   SUBJECTS    RESPONSES   EXPECTED    DEVIATION    PROBABILITY
14  V-72             68.         13.       12.222        .778        .179731
15                   77.         26.       27.974      -1.974        .363296
16                   76.         38.       38.716       -.716        .509427
17                   79.         55.       52.339       2.661        .662517
18                   79.         69.       69.729       -.729        .882652

19  CHI-SQUARE    .7721       DEGREES OF FREEDOM   3       HETEROGENEITY   .26

20  INDEX OF SIGNIFICANCE FOR POTENCY ESTIMATION:   G(.90)=.032782   G(.95)=.046545   G(.99)=.080392

21  EFFECTIVE DOSES                       LIMITS (0.90)          LIMITS (0.95)          LIMITS (0.99)
22                          DOSE        LOWER     UPPER        LOWER     UPPER        LOWER     UPPER
23  LD10    V-72           .02159       .01616    .02657       .01508    .02748       .01293    .02921
24  LD50    V-72           .06852       .06153    .07607       .06020    .07764       .05756    .08091
25  LD90    V-72           .21753       .17895    .28504       .17338    .30409       .16366    .35093
```

CHORISTONEURA SPECIES. RESMETHRIN

Page 3

INTERCEPTS AND SLOPES UNCONSTRAINED. PREPARATION IS (2) L-74
ESTIMATING NATURAL RESPONSE

MAXIMUM LOG-LIKELIHOOD -148.89633

	PARAMETER	STANDARD ERROR	T RATIO
L-74	2.3059541	.30239034	7.6257532
NATURAL	.19658712-01	.73582634-02	2.6716511
SLOPE	2.9210015	.40333053	7.2422027

VARIANCE-COVARIANCE MATRIX

	L-74	NATURAL	SLOPE
L-74	.9143992-01	.4464050-04	.1153509
NATURAL	.4464050-04	.5414404-04	.1677648-03
SLOPE	.1153509	.1677648-03	.1626755

CHI-SQUARED GOODNESS OF FIT TEST

D2

PREPARATION	SUBJECTS	RESPONSES	EXPECTED	DEVIATION	PROBABILITY
L-74	70.	22.	19.854	2.146	.283627
	49.	27.	29.988	-2.988	.611992
	50.	38.	39.309	-1.309	.786187
	50.	48.	46.233	1.767	.924669
NATURAL	359.	7.	7.057	-.057	.019659

CHI-SQUARE 2.1914 DEGREES OF FREEDOM 2 HETEROGENEITY 1.0957

A LARGE CHI-SQUARE INDICATES A POOR FIT OF THE DATA BY THE PROBIT ANALYSIS MODEL. LARGE DEVIATIONS FOR EXPECTED PROBABILITIES NEAR 0 OR 1 ARE ESPECIALLY TROUBLESOME. A PLOT OF THE DATA SHOULD BE CONSULTED. SEE D. J. FINNEY, 'PROBIT ANALYSIS' (1972), PAGES 70-75.

INDEX OF SIGNIFICANCE FOR POTENCY ESTIMATION: G(.90)= .178120 G(.95)= .386744 G(.99)= 2.0577

'WITH ALMOST ALL GOOD SETS OF DATA, G WILL BE SUBSTANTIALLY SMALLER THAN 1.0, AND SELDOM GREATER THAN 0.4'
- D. J. FINNEY, 'PROBIT ANALYSIS' (1972), PAGE 79.

WE WILL USE ONLY THE PROBABILITIES FOR WHICH G IS LESS THAN 0.5

EFFECTIVE DOSES

			LIMITS (0.90)		LIMITS (0.95)		LIMITS (0.99)	
		DOSE	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER
LD10	L-74	.05913	.02342	.08892	.00765	.10122		
LD50	L-74	.16239	.11817	.20596	.08913	.23428		
LD90	L-74	.44596	.32421	.87723	.29083	1.93634		

CHORISTONEURA SPECIES. RESMETHRIN

Page 4

INTERCEPTS AND SLOPES UNCONSTRAINED. PREPARATION IS (3) C-74
NOT ESTIMATING NATURAL RESPONSE

MAXIMUM LOG-LIKELIHOOD -145.29642

	PARAMETER	STANDARD ERROR	T RATIO
C-74	3.5925928	.47857456	7.5068613
SLOPE	2.5975633	.35252155	7.3685234

VARIANCE-COVARIANCE MATRIX

	C-74	SLOPE
C-74	.2290336	.1660245
SLOPE	.1660245	.1242714

CHI-SQUARED GOODNESS OF FIT TEST

D3

PREPARATION	SUBJECTS	RESPONSES	EXPECTED	DEVIATION	PROBABILITY
C-74	48.	12.	9.885	2.115	.205940
	50.	15.	17.912	-2.912	.358235
	50.	31.	29.218	1.782	.584370
	48.	31.	34.718	-3.718	.723296
	59.	52.	49.568	2.432	.840139

CHI-SQUARE 3.7541 DEGREES OF FREEDOM 3 HETEROGENEITY 1.2514

A LARGE CHI-SQUARE INDICATES A POOR FIT OF THE DATA BY THE PROBIT ANALYSIS MODEL. LARGE DEVIATIONS FOR EXPECTED PROBABILITIES NEAR 0 OR 1 ARE ESPECIALLY TROUBLESOME. A PLOT OF THE DATA SHOULD BE CONSULTED. SEE D. J. FINNEY, 'PROBIT ANALYSIS' (1972), PAGES 70-75.

INDEX OF SIGNIFICANCE FOR POTENCY ESTIMATION: G(.90)=.127647 G(.95)=.233426 G(.99)=.786298

'WITH ALMOST ALL GOOD SETS OF DATA, G WILL BE SUBSTANTIALLY SMALLER THAN 1.0, AND SELDOM GREATER THAN 0.4'
- D. J. FINNEY, 'PROBIT ANALYSIS' (1972), PAGE 79.

WE WILL USE ONLY THE PROBABILITIES FOR WHICH G IS LESS THAN 0.5

EFFECTIVE DOSES

			LIMITS (0.90)		LIMITS (0.95)		LIMITS (0.99)	
		DOSE	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER
LD10	C-74	.01329	.00638	.01924	.00392	.02112		
LD50	C-74	.04139	.03279	.05062	.02926	.05482		
LD90	C-74	.12892	.09351	.24008	.08611	.36089		

CHORISTONEURA SPECIES, RESMETHRIN

Page 5

INTERCEPTS AND SLOPES CONSTRAINED (LINES ARE THE SAME)
NOT ESTIMATING NATURAL RESPONSE

MAXIMUM LOG-LIKELIHOOD -549.84206

	PARAMETER	STANDARD ERROR	T RATIO
INTERCPT	1.8011430	.15715077	11.461242
SLOPE	1.5271831	.13708161	11.140685

VARIANCE-COVARIANCE MATRIX

	INTERCPT	SLOPE
INTERCPT	.2469636-01	.2061895-01
SLOPE	.2061895-01	.1879137-01

TESTING HYPOTHESIS THAT SLOPES AND INTERCEPTS ARE THE SAME
CHI-SQUARE=83.29068 D.F.=4 TAIL PROBABILITY=.000
HYPOTHESIS REJECTED

CHI-SQUARED GOODNESS OF FIT TEST

E

PREPARATION	SUBJECTS	RESPONSES	EXPECTED	DEVIATION	PROBABILITY
INTERCPT	68.	13.	20.396	-7.396	.299941
	77.	26.	32.826	-6.826	.426313
	76.	38.	39.134	-1.134	.514915
	79.	55.	48.027	6.973	.607942
	79.	69.	60.706	8.294	.768431
	70.	22.	43.095	-21.095	.615650
	49.	27.	37.876	-10.876	.772983
	50.	38.	42.254	-4.254	.845082
	50.	48.	45.594	2.406	.911874
	48.	12.	10.260	1.740	.213745
	50.	15.	14.997	.003	.299941
	50.	31.	21.316	9.684	.426313
	48.	31.	24.716	6.284	.514915
	59.	52.	35.869	16.131	.607942

CHI-SQUARE 88.521 DEGREES OF FREEDOM 12 HETEROGENEITY 7.3768

A LARGE CHI-SQUARE INDICATES A POOR FIT OF THE DATA BY THE PROBIT ANALYSIS MODEL. LARGE DEVIATIONS FOR EXPECTED PROBABILITIES NEAR 0 OR 1 ARE ESPECIALLY TROUBLESOME. A PLOT OF THE DATA SHOULD BE CONSULTED. SEE D. J. FINNEY, 'PROBIT ANALYSIS' (1972), PAGES 70-75.

INDEX OF SIGNIFICANCE FOR POTENCY ESTIMATION: G(.90)=.188799 G(.95)=.282152 G(.99)=.554542

'WITH ALMOST ALL GOOD SETS OF DATA, G WILL BE SUBSTANTIALLY SMALLER THAN 1.0, AND SELDOM GREATER THAN 0.4'
- D. J. FINNEY, 'PROBIT ANALYSIS' (1972), PAGE 79.

WE WILL USE ONLY THE PROBABILITIES FOR WHICH G IS LESS THAN 0.5

EFFECTIVE DOSES			LIMITS (0.90)		LIMITS (0.95)		LIMITS (0.99)	
		DOSE	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER
LD10	INTERCPT	.00958	.00177	.01931	.00081	.02148		
LD50	INTERCPT	.06616	.04319	.09282	.03728	.10121		
LD90	INTERCPT	.45685	.25117	1.87048	.22894	3.58864		

CHORISTONEURA SPECIES, RESMETHRIN

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SLOPES CONSTRAINED (LINES ARE PARALLEL)
NOT ESTIMATING NATURAL RESPONSE

MAXIMUM LOG-LIKELIHOOD -508.49591

	PARAMETER	STANDARD ERROR	T RATIO
V-72	3.0874235	.23160595	13.330502
L-74	2.1164657	.16702207	12.671773
C-74	3.6677209	.27134493	13.516821
SLOPE	2.6537986	.19280724	13.763999

VARIANCE-COVARIANCE MATRIX

	V-72	L-74	C-74	SLOPE
V-72	.5364132-01	.3011145-01	.5684569-01	.4254397-01
L-74	.3011145-01	.2789637-01	.3515604-01	.2631118-01
C-74	.5684569-01	.3515604-01	.7362807-01	.4967138-01
SLOPE	.4254397-01	.2631118-01	.4967138-01	.3717463-01

TESTING HYPOTHESIS THAT SLOPES ARE THE SAME
CHI-SQUARE=.59838 D.F.=2 TAIL PROBABILITY=.741
HYPOTHESIS ACCEPTED

CHI-SQUARED GOODNESS OF FIT TEST

F

PREPARATION	SUBJECTS	RESPONSES	EXPECTED	DEVIATION	PROBABILITY
V-72	68.	13.	11.563	1.437	.170044
	77.	26.	27.525	-1.525	.357463
	76.	38.	38.684	-.684	.508994
	79.	55.	52.750	2.250	.667720
	79.	69.	70.398	-1.398	.891118
L-74	70.	22.	21.656	.344	.309368
	49.	27.	29.937	-2.937	.610963
	50.	38.	38.577	-.577	.771535
	50.	48.	45.401	2.599	.908024

```
C-74            48.        12.        9.608       2.392       .200173
                50.        15.       17.716      -2.716       .354316
                50.        31.       29.257       1.743       .585136
                48.        31.       34.881      -3.881       .726694
                59.        52.       49.837       2.163       .844690

CHI-SQUARE   7.1432      DEGREES OF FREEDOM  10       HETEROGENEITY   .71

INDEX OF SIGNIFICANCE FOR POTENCY ESTIMATION:   G(.90)=.014281   G(.95)=.020277   G(.99)=.035022


EFFECTIVE DOSES                       LIMITS (0.90)             LIMITS (0.95)              LIMITS (0.99)
                         DOSE        LOWER      UPPER         LOWER      UPPER          LOWER      UPPER
LD10    V-72           .02258       .01868     .02639        .01792     .02711         .01644     .02852
        L-74           .05243       .04163     .06355        .03961     .06572         .03569     .06999
        C-74           .01365       .01107     .01624        .01058     .01674         .00962     .01772

LD50    V-72           .06864       .06199     .07591        .06076     .07741         .05838     .08045
        L-74           .15940       .13806     .18293        .13415     .18778         .12662     .19768
        C-74           .04149       .03663     .04685        .03573     .04796         .03401     .05023


CHORISTONEURA SPECIES. RESMETHRIN


EFFECTIVE DOSES                       LIMITS (0.90)             LIMITS (0.95)              LIMITS (0.99)
                         DOSE        LOWER      UPPER         LOWER      UPPER          LOWER      UPPER
LD90    V-72           .20870       .17983     .24981        .17525     .25977         .16697     .28188
        L-74           .48461       .41149     .58588        .39969     .61001         .37820     .66312
        C-74           .12614       .10767     .15214        .10472     .15840         .09937     .17225


RELATIVE POTENCIES
                                 LIMITS (0.90)           LIMITS (0.95)           LIMITS (0.99)
                  POTENCY      LOWER     UPPER         LOWER     UPPER         LOWER     UPPER
L-74              .43065       .36324    .51299        .35156    .53111        .32964    .56930
C-74             1.65450      1.41251   1.94143       1.36986   2.00342       1.28923   2.13284
```

G

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CHORISTONEURA SPECIES. RESMETHRIN                                           PAGE 1
  V-72        SUBJECTS 379    CONTROLS 40       PAGE 2
    LOG(L)=-214.0    SLOPE=2.55+-.28    NAT.RESP.=.000+-.000
    HETEROGENEITY=.26    G=.05
    LD10=.022    LIMITS: .015 TO .027
    LD50=.069    LIMITS: .060 TO .078
    LD90=.218    LIMITS: .173 TO .304
  L-74        SUBJECTS 219    CONTROLS 359      PAGE 3
    LOG(L)=-148.9    SLOPE=2.92+-.40    NAT.RESP.=.020+-.007
    HETEROGENEITY=1.10    G=.39
    LD10=.059    LIMITS: .008 TO .101
    LD50=.162    LIMITS: .089 TO .234
    LD90=.446    LIMITS: .291 TO 1.936
  C-74        SUBJECTS 255    CONTROLS 30       PAGE 4
    LOG(L)=-145.3    SLOPE=2.60+-.35    NAT.RESP.=.000+-.000
    HETEROGENEITY=1.25    G=.23
    LD10=.013    LIMITS: .004 TO .021
    LD50=.041    LIMITS: .029 TO .055
    LD90=.129    LIMITS: .086 TO .361
  SAME        SUBJECTS 853    CONTROLS 429      PAGE 5
    LOG(L)=-549.8    SLOPE=1.53+-.14    NAT.RESP.=.016+-.000
    HYPOTHESIS REJECTED
    HETEROGENEITY=7.38    G=.28
    LD10=.010    LIMITS: .001 TO .021
    LD50=.066    LIMITS: .037 TO .101
    LD90=.457    LIMITS: .229 TO 3.589
  PARALLEL    SUBJECTS 853    CONTROLS 429      PAGE 6
    LOG(L)=-508.5    SLOPE=2.65+-.19    NAT.RESP.=.016+-.000
    HYPOTHESIS ACCEPTED
    HETEROGENEITY=.71    G=.02
    LD10=.023    LIMITS: .018 TO .027
    LD50=.069    LIMITS: .061 TO .077
    LD90=.209    LIMITS: .175 TO .260
```

H

CHORISTONEURA SPECIES. RESMETHRIN

PREP	N	NC	C	SE	BETA	SE	LD50	95% LIMITS		LD90	95% LIMITS		HET	G	LOG
V-72	379	40	.000		2.55	.28	.07	.06	.08	.22	.17	.30	.26	.05	-214.
L-74	219	359	.020	.007	2.92	.40	.16	.09	.23	.45	.29	1.94	1.10	.39	-148.
C-74	255	30	.000		2.60	.35	.04	.03	.05	.13	.09	.36	1.25	.23	-145.
EQUAL	853	429			1.53	.14	.07	.04	.10	.46	.23	3.59	7.38	.28	-549.
PARALLEL	853	429			2.65	.19	.07	.06	.08	.21	.18	.26	.71	.02	-508.

@FIN

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This user's guide provides detailed instructions for the use of POLO (*P*robit *O*r *LO*git), a computer program for the analysis of quantal response data such as that obtained from insecticide bioassays by the techniques of probit or logit analysis. Dosage-response lines may be compared for parallelism or equality by means of likelihood ratio tests. Statistical features of the program, suggestions for the design of experiments that provide data for analysis, and formats for data input and output are described in detail.

Retrieval Terms: bioassay, logit analysis, probit analysis.

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Risk-Rating Systems for Mature Red Fir and White Fir in Northern California

George T. Ferrell

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IN BRIEF...

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1980. **Risk-rating systems for mature red fir and white fir in north n California.** Gen. Tech. Rep. PSW-39, 29 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berke /, Calif.
Retrieval Terms: Abies concolor, Abies magnifica, California, mortality, k rating, bark boring insects.

Risk-rating systems predicting the probability that a tree will die within years have been developed for mature red fir and white fir in norther California. The systems are based on analysis of the crown and bole charac teristics of trees. For field use, the systems are formulated into Award Penalty Point Systems, in which a tree is awarded points on the basis o ratings of some characteristics and penalized points on the basis of ratings o others. The difference between the Award and Penalty Point Totals— termed the Risk Point Total—is related to the percentage of a hypothetica population of identical trees that are expected to die within 5 years.

The systems are applicable to firs at least 10 inches (25.4 cm) in d.b.h. growing in mature stands, with the original overstory at least partially intact in northern California. Outside this range in central and southern California the systems may be used only tentatively, pending the results of studie underway to test, and verify or modify, the systems in these areas.

The risk-rating systems were developed by characterizing living an recently dead firs during initial surveys of 47 plots, each 20 acres (8.1 ha) i area, in northern California during the years 1975-1977. Totals of 1012 re firs (851 live, 161 dead), and 2571 white firs (2430 live, 141 dead) more tha 10 inches (25.4 cm) in d.b.h. were examined in virgin and cutover stands Tree characteristics were screened by computer to select variables capable o predicting tree death. For red fir, the risk predictors selected were Crow Class, Live Crown Percent, Top Condition, and Percent Crown Raggednes (Ragged Percent). For white fir they were Percentage of Crown wit branches oriented horizontally or upswept (Branch Angle Percent), Crow Density, Percent Crown Raggedness (Ragged Percent) and whether livin inner bark was visible in bark crevices at breast height (Bark Fissures).

By using these predictor variables, regression equations in the form o logistics functions were developed to predict the probability of a tree's deat within 1 year. These probabilities were extrapolated to probabilities of deat within 5 years by using a variant of a standard compound interest formula The risk equations adequately explained the mortality in the data base whe the distributions of expected and observed mortalities were compared b chi-square goodness-of-fit tests.

The risk equations were directly translated into Award-Penalty Poin Systems in which trees are awarded points on the basis of predictors wit positive regression coefficients, and penalized points on the basis of predict ors with negative coefficients.

Red fir (*Abies magnifica* A. Murr.) and white fir (*A. concolor* [Gord. and Glend.] Lindl.), are major components of conifer stands at elevations f 700 to 3000 m in California. Although they vary from repeatedly logged virgin and show a range of structures, these stands frequently retain intact uch of the original overstory of mature trees. To meet management bjectives for these stands, it is often desirable to maintain some semblance f this original structure by selectively harvesting overstory trees. Among e many criteria for deciding which trees to remove, the probability of mminent tree death resulting from natural causes—disease, insects, veather—is frequently overriding, especially if death is anticipated some ears before the next planned reentry of the stand for harvesting.

In addition to harvesting timber before it dies and deteriorates, thereby voiding the hazard of standing dead trees, it is desirable to identify and emove weakened trees to prevent their being used as substrate by insects nd diseases.

An outgrowth of tree vigor classifications designed primarily for silvicul- ural purposes (Dunning 1928), risk-rating systems have been developed for lassifying mature ponderosa and Jeffrey pines according to risk of being illed by *Dendroctonus* bark beetles (Keen 1936, 1943; Keen and Salman 942; Salman and Bongberg 1942; Struble 1965). Use of the Salman- ongberg system, followed by sanitation-salvage logging, has been suc- essful in reducing or preventing beetle-caused pine mortality in both north- astern (Wickman and Eaton 1962) and southern (Hall 1958) California. his system also applies, with little or no modification, to ponderosa pines in e Southwest (Pierce 1961) and in western Montana (Johnson 1972).

To be practical, risk-rating systems should be rapid and easy to use, pecies-specific, and provide reliable estimates of risk for trees managed for variety of objectives. Such systems have not been available previously for ed fir and white fir. On the basis of a single year's results (1941), the onderosa Pine Risk System of Salman and Bongberg appeared to apply to hite fir in northeastern California, but the study was discontinued.[1] Al- hough this system has been widely applied to true firs on an empirical basis, ese species differ sufficiently from ponderosa pine in silvicultural charac-

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[1]Hall, R.C. Preliminary results of risk-rating all coniferous tree species on the Hat Creek udy plots. (Unpublished report on file at the Pacific Southwest Forest and Range Exp. Stn., erkeley, Calif.)

teristics and in the pest complexes attacking them to justify separate risk rating systems. Local, unverified systems have also been used for these firs White firs rated as "high risk" by such a system, and those recently killed by subcortical insects, were found to have high densities of old fir engrave (*Scolytus ventralis* Le Conte) attack scars embedded in their boles, indicating increased susceptibility to the beetles (Ferrell 1973). Although data were fragmentary, these results indicated that reliable risk-rating systems could be devised for these firs.

This paper describes studies designed to develop, test, and extend the risk-rating systems for mature red fir and white fir in northern California Properly used, these systems should contribute to the sound, long-term management of California's true firs.

DATA COLLECTION

Mortality plots

Forty-seven mortality plots, each 20 acres (8.1 ha) in area, were established from 1975 to 1977 to characterize dead and living firs and to monito changes in the latter during the life of the study. White fir and red fir occupy extensive, partially overlapping ranges in California, within which both species display considerable geographic variation (Griffin and Critchfield 1972). To sample only part of this range and yet include as much variation as possible, the Cascade and Siskiyou Mountains north of Lassen Peak were selected for initial study. Shasta red fir (var. *shastensis* Lemm.) is usually found in this region, and near the Oregon border in northwest California white fir and red fir become increasingly intermediate in certai morphological and chemical characteristics, with *Abies grandis* (Dougl. Lindl., and *A. procera* Rehd., respectively (Zavarin and others 1975, 1978)

Within the region selected the plots, by National Forest, were distribute as follows: Lassen National Forest—33 plots located on both west and eas sides of the Cascade crest from the vicinity of Lassen Peak north to the P River; Shasta-Trinity National Forest—5 plots on the east side of th Cascade crest from the Pit River north to Mt. Shasta; Klamath Nationa Forest—4 plots on the Siskiyou crest northwest of Mt. Shasta. In addition five plots were located on the west side of the central Sierra Nevada crest i the Stanislaus National Forest to sample white fir infected by a leaf mistletoe (*Phoradendron bolleanum* spp. *pauciflorum* [Torr.] Wiens). Thi mistletoe is a risk factor (Felix and others 1971, Ferrell 1974) that wa reported as not occurring north of the Mokelumne River drainage in th central Sierra Nevada (Wagener 1957).

As the plots were concentrated in the Cascade and Siskiyou Mountains the resulting risk systems should apply mainly in this region, and it wa expected that further sampling, testing, and if necessary, modification of th

ystems would be required to make them applicable to other regions of California in which these firs occur.

Stands sampled by the plots had to meet certain criteria. They had to be "mature;" that is, with mature red or white fir, or both, comprising at least 0 percent of the overstory. The stand could be either virgin or cutover, but if utover, the original overstory had to be at least partially intact. Also, the tand must not have been logged within the preceding 3 years, nor scheduled or logging for the next 5 years. Finally, the stand structure had to be as niform as possible throughout the area of at least 20 acres.

Plots were selected by systematic examination of ¼-mile-wide roadside trips, and by sampling every stand that met the selection criteria. The plots id not constitute a random sample of all stands containing white and red firs n northern California, but they were considered to be a representative ross-section of most growing sites for these firs in the region studied. Twenty plots were established in 1975, 22 in 1976, and five in 1977. In the egion sampled, the ranges of white fir and red fir broadly overlap at levations of 1300 to 2300 m. Consequently, 29 of the plots contained both pecies, 12 had white fir only, and 6 had red fir only. Among the 47 plots, 26 ad been logged—although many only lightly so—and 21 were virgin ld-growth.

Each summer, after the crowns of firs dying since the previous summer ad faded, each plot was completely surveyed and the characteristics of hese faded firs recorded. Only firs 10 inches (25.4 cm) or more in d.b.h. were sampled. Also, during initial survey of each plot, an additional sample f obviously declining firs—"poor vigor" trees—was characterized to tudy rates of crown change. These trees were marked so that they could be eexamined annually. The number of firs selected for this purpose varied rom plot-to-plot according to their availability, but an attempt was made to mark at least eight per plot.

Green Stand Subplots

Because of the scattered distribution of tree mortality when pest populations are endemic, dead trees were sampled in 20-acre plots. The high ratio f live-to-dead firs on these plots, however, made it infeasible to characterize all of the living firs on the entire 20 acres. Consequently, a subsample f the "green stand" was obtained by characterizing all living firs exceeding he minimum d.b.h. on a 1-acre (0.4-ha) green stand subplot. These firs were also marked so that they could be reexamined for changes in condition uring the annual surveys. Although the sample stands were chosen to be as niform as possible, considerable variation in forest cover within the mortality plots was inevitable because of their size. Each subplot was elected by noting variations in forest cover during the initial survey and by electing a subplot that approximated the average stand structure, density, nd species composition on the mortality plot. This method effectively

avoided the selection of subplots with unrepresentative forest cover and hopefully, any bias possibly introduced by the nonrandomness of the metho did not seriously affect the ability of the subplots to represent living firs o the mortality plots for purposes of risk calculations.

Tree Characteristics

To be practical, a risk-rating system should use only a few tree charac teristics, carefully chosen for their value as risk predictors. Predictors shoul be externally visible and capable of evaluation by rapid visual estimate o rating.

To ensure that this system could predict current and long-term risks predictors of both were included in the study. Systems developed fo ponderosa pine were valuable in suggesting characteristics to be studied i firs. Indicators of age (for example, bark color) and vigor (for example, liv crown length) were used for long-term risk (Keen 1936); crown weakenin and top condition were used as indicators of current risk (Salman an Bongberg 1942). Indicators selected from each pine system, living togethe with additional characteristics not previously used, were investigated fo their value as fir risk predictors. Most characteristics could be estimated o

Table 1—*Tree characteristics evaluated as risk predictors*

Characteristic	Definition
D.b.h.	Bole diameter at breast height
Live crown percent	Percent of tree height in live crown
Cortex percent	Percent of tree height with smooth bark
Bole condition	Presence of scars caused by sapsuckers, beetle attack, lightning c logging; bole cankers
Bark fissures	Live inner bark visible (or not) in fissures
Bole scar percent	Percent of bole circumference scarred
Lightning scar percent	Percent of bole circumference scarred by lightning
Sapsucker scar percent	Percent of bole circumference scarred by sapsuckers
Bole cankers	Number of bole cankers
Mistletoe masses	Vertical extent of leafy mistletoe clumps
Crown width	Maximum width of crown
Branch angle percent	Percent of crown length with upswept to horizontal branches
Crown density	Density and raggedness of crown
Ragged percent	Percent of crown missing, dead, or dying
Top condition	Shape and condition (spike, topkill) of top
Topkill percent	Percent of crown length recently killed
Spike percent	Percent of crown length in old topkill
Crown class	Crown position in stand canopy
Tree height	Total height of tree
Tree age	Young or mature as less than, or greater than, 80 to 100 years olc
Bark color	Color of dead bark at breast height
Foliage color	Normal, or abnormal (chlorotic, browned), color

rated by visual inspection. Some, however, required measurement to ensure sufficient accuracy of the data base, but were able to be estimated when used in practice to risk-rate trees. Although many characterisitcs were studied (*table 1*), only the most reliable predictors were included in the risk systems.

Mortality Agents

In addition to damage estimates for externally visible pests, such as mistletoes (crown raggedness, bole cankers), and woodpeckers (sapsucker scars), which were estimated in all sampled firs, dead and dying firs were also examined for subcortical pests possibly implicated in tree death. Boles were chopped into at breast height and at ground level, and the wood-bark interface was examined for evidence of subcortical beetles and root decay fungi. Beetles were identified by their borings or gallery patterns, or by any adults present (Keen 1952, Furniss and Carolin 1978). Root decay fungi were identified by their sporophores, rhizomorphs, mycelia, or the wood stains and decays produced (Hepting 1971, Smith 1978).

DATA ANALYSIS

Two complementary methods of analysis designed to provide for the early development of preliminary risk systems and, at the same time to lead to the development of final systems, were used. In both methods, the characteristics of dead and dying firs were compared with those of surviving firs.

Analysis of Initial Mortality

To develop the preliminary systems, the characteristics of firs judged to be recently dead during initial surveys of the mortality plots were compared with those of living firs within the green stand subplots. Because the plots were established in the years 1975 to 1977, the analysis, although considered adequate for preliminary systems, lacked the time-span required for development of final risk systems.

One drawback, inherent in the method of post-mortem examination of trees, was that characterization of the condition of the tree pertained only to the period just before it died. Also, certain pre-death characteristics were not obtainable. Color of the foliage before death, for example, was not obtainable from the dead tree. Other characteristics required interpretation; that is, topkilling occurring some years before tree death, denoted by branches bare of foliage, was judged to be recent or older, depending upon whether the fine twigs were still in place, or had been shed. Most of the characteristics used in the study, however, had not been altered by tree death and could be evaluated directly by post-mortem examination.

Derived solely from post-mortem examination of firs dying within 3-year period, the resulting risk systems, reported here, are considere preliminary to final systems being developed by the following method.

Analysis of Mortality Over Time

Living firs characterized within the green stand subplot, as well as ''poo vigor'' trees scattered over the entire mortality plot, were surveyed annuall for changes in tree characteristics or mortality. This method is advantageou in that tree condition will be monitored over some years, in advance of death allowing the development of rating systems capable of predicting long-tern risk. The surveys will continue until adequate data upon which to base th final systems are obtained, as described later in this report.

Identifying Risk Predictors

To identify those traits of greatest value as risk predictors, tree charac teristics were screened by the computer program SCREEN (Hamilton an Wendt 1975). Continuous variables (percentages or measurements) wer subdivided into intervals or classes, as required by the Program. Comparin ratios in the numbers of dead-to-living trees, the Program screens the tre characteristics in step-wise fashion, selecting at each step the most signifi cant predictor variable on the basis of user-specified levels of chi-squar probability. The selective search principle upon which the choice of vari ables is made uses an algorithm based on assumptions that cannot, a present, be proven (Sterling and others 1969). Consequently, the method although not guaranteeing results as valid as those from an exhaustive searc of all variables, represents the best of the practical alternatives available

Output from the Program, in the form of a ''decision tree'' diagran *(fig. 1)*, arranged the variables from left to right along the tree's ''branches,'' with each variable statistically explaining the largest amount of the mortalit occurring in the interval or class to the immediate left. Intervals or classe with dissimilar mortality ratios were listed separately; those with simila ratios were combined. This method of screening identified variables tha provided additional information about the mortality in groups of trees fallin within particular intervals or classes of variables already selected.

In both tree species, more variables were significant at the 95 percent leve than were usable in a practical risk system. Only those significant variable selected either early in the step-wise process, or in more than one branch o the decision tree, and convenient for field estimation, were included in th risk calculations. The variables included, therefore, were those that were th most significant indicators of risk for as many of the sample firs as possibl with the expectation that as risk predictors, they would perform similarly fo most trees risk-rated in practice. Further analysis of the larger data bas accumulated by the end of the study, however, may result in the inclusion o other variables to supplant or augment those in the present system.

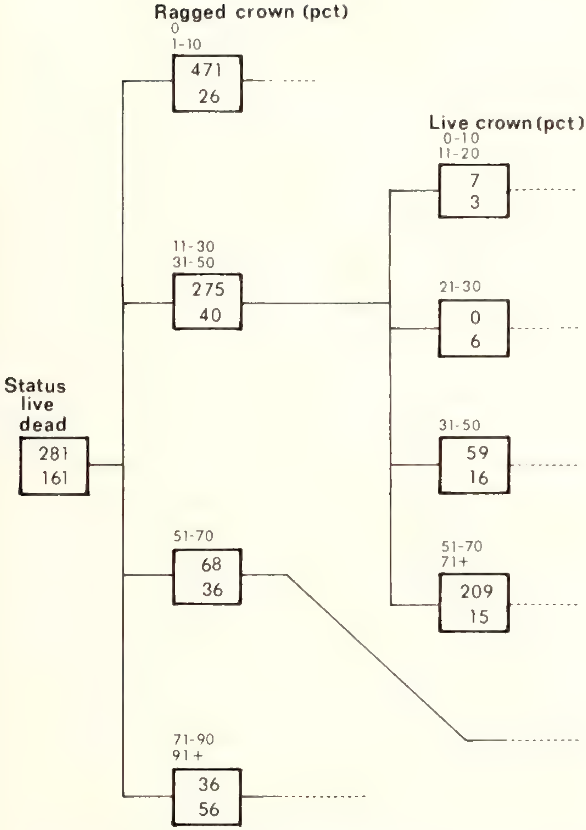

Figure 1—Portion of the "decision tree" produced by screening characteristics of mature red firs for value as risk predictors. Numbers above each box specify interval, or classes of the variables named above. Upper and lower numbers in boxes are the number of live and dead trees, respectively, in the intervals or classes. Intervals with similar mortality ratios are combined. The total numbers of live and dead firs sampled are shown under STATUS. Dashed lines extending to right from tree numbers indicate additional "branches" not shown.

Risk Calculations

Tree characteristics selected by the screening process were used as independent variables in the computer program RISK (Hamilton 1974). This Program calculates regression equations predicting risk of tree death. The equations predict the probability of individual tree death as a decimal between zero and 1, by using a logistics function of the form:

$$P=1/(1+e^{X})$$

in which e is the base of natural logarithms, and X is a vector of the tree's

characteristics. Graphically, the logistics equation is a sigmoid-shaped curve that Monserud (1976) found had greater power for predicting tree death than either discriminant, or probit, analysis.

The trees were sampled with unequal probability: living firs were sampled within 1-acre subplots and dead trees were sampled over 20-acre plots. To place the trees on an equal-area basis for calculation of risk probabilities, each live tree was weighted by an expansion factor of 20 in regression calculations. The assumption was that, on the average, each live fir on the subplot was represented by 20 similar living firs on the mortality plot.

Ability of the equations to explain statistically the observed distribution of fir mortality in the data base was judged by chi-square goodness-of-fit test (Hamilton 1974). Equations predicting the probability of death within 1 year were used to generate the distribution of estimated probabilities in the unweighted samples of firs. The distributions of observed and predicted mortality in the samples were then compared over the range of probabilities predicted by the equations.

Because the resulting risk equations were based mainly on firs that had died within 1 year before sampling (''initial mortality''), the resulting probabilities were considered to predict the risk of a tree's dying within 1 year. The stand manager, however, is primarily interested in predicting tree risk over somewhat longer time periods. Using the 1-year probabilities (P_1), the probability of death within 5 years (P_5) was calculated from the relationship:

$$P_n = 1 - (1 - P_1)^n$$

in which $n = 5$ (Hamilton and Edwards 1976). The calculated probabilities were expressed either as decimals, or multiplied by 100 percent to obtain the percentage of a population of identical trees expected to die within a 5-year period.

RISK EQUATIONS

Red Fir

On the basis of screening the characteristics of the unweighted sample of 1012 mature red firs (851 live, 161 dead), Crown Class, Live Crown Percent, Top Condition, and Ragged Percent were selected as significant risk predictors.

From regression analysis of this sample of firs, the relationship for X in the equation $P_1 = 1/(1 + e^X)$, predicting probability of death within 1 year (P_1) was:

$$X = 3.096 + 0.159\ \mathrm{CCLS} + 0.049\ \mathrm{CPCT}$$
$$- 0.010\ \mathrm{TCON} - 0.036\ \mathrm{RPCT}$$

in which

CCLS = Crown Class as one of following codes: (0) Suppressed, (1) Intermediate, (2) Codominant, (3) Dominant.

CPCT = Live Crown Percent as percentage of tree height in living crown estimated to nearest 10 percent (ignore isolated lower branches).

TCON = Top Condition as one of following codes: (0) Pointed, (1) Round, (2) Flat, (3) Broken with live regrown leader(s), (4) Spike with live regrown leader(s), (5) Broken without live regrown leader(s), (6) Spike without live regrown leader(s), and (7) Recent topkill.

RPCT = Ragged Percent as percentage of crown missing, dead, or faded estimated to nearest 10 percent (ignore isolated lower branches).

The chi-square goodness-of-fit test *(table 2)* indicated that the probability distributions of predicted and observed mortality did not differ significantly (χ^2 = 1.03, 6 df), indicating the equation adequately predicted the observed distribution of mortality in the sample.

Table 2—*Distribution of mature fir samples in intervals of predicted probability of death within 1 year, and goodness-of-fit of observed to predicted mortality, compared by chi-square for the range of prediction*

Interval	Number of trees in interval			Chi-square
	Total[1]	Dead: Observed	Dead: Predicted	
	Red fir (N = 1012)			
0.00 to 0.01	798.6	2.7	2.5	0.01
.01 to .05	178.8	3.1	3.8	.12
.05 to .10	23.2	2.0	1.6	.11
.10 to .15	8.2	1.1	0.9	.04
.15 to .20	3.9	0.4	0.7	.18
.20 to .25	0.2	0.2	0.0	.47
.25 to .30	0.1	0.1	0.0	.10
		Total chi-square =		1.03 (6 df)[2]
	White fir (N = 2571)			
0.00 to 0.01	2395.1	3.5	3.3	0.01
.01 to .05	161.1	1.8	3.2	.58
.05 to .10	14.1	1.4	0.9	.24
.10 to .15	0.7	0.7	0.1	4.78
		Total chi-square =		5.61 (3 df)

[1]Living plus dead firs.

[2]Probability distributions of predicted and observed mortality did not differ significantly, therefore the equations adequately predicted the occurrence of tree mortality in the firs sampled.

White Fir

On the basis of screening the characteristics of the unweighted sample of 2571 mature white firs (2430 live, 141 dead), Branch Angle Percent, Crown Density, Ragged Percent, and Bark Fissures were selected as significant risk predictors.

From regression analysis of this sample of firs, the relationship of X in the equation $P_1 = 1/(1 + e^X)$, predicting probability of death within 1 year (P_1) was:

$$X = 9.643 + 0.032\ \text{BANG} - 0.078\ \text{CDEN} - 0.047\ \text{RPCT} - 1.419\ \text{BFIS}$$

in which

BANG = Branch Angle Percent. Percentage of crown length with branches horizontal or unturned, estimated to nearest 10 percent.

CDEN = Crown Density as one of the following codes: (0) Dense (normal) foliage, (1) Ragged, one-sided, crown missing on one or more sides because of being raked by falling neighbor tree, or because of competition (shading) from neighbor tree, (2) Ragged, dead and flagged, crown ragged as a result of dead and/or dying branches scattered throughout crown, (3) Ragged because of combination of (1) and (2), (4) Thin, crown uniformly thinner than normal.

RPCT = Ragged Percent as the combined percentage of crown raggedness because of scattered missing, dead, and dying branches and one-sided crown.

BFIS = Bark Fissures as one of the following codes: (1) Live—Living bark visible between dead bark plates, (2) Dead—Living bark not visible between dead bark plates.

The chi-square goodness-of-fit test *(table 2)* suggests that the probability distributions of predicted and observed mortality did not differ significantly ($\chi^2 = 5.62$, 3 df), indicating the equation adequately predicted the observed distribution of mortality in the sample.

More complete definitions of the above predictors, together with instructions for using them to rate trees, can be found in the *Appendix*.

Using the Equations

Examples of rating risk by using the equations, and the effects of some of the predictors on the calculated risk are illustrated *(figs. 2,3,4)*.

Crown raggedness was the major risk predictor in both fir species. Crowns were frequently one-sided, with all or part of the crown missing or dead on one side because of shading from a neighboring tree or because of being raked when a neighboring tree fell. Also frequent were crowns ragged from scattered dead and dying branches, frequently resulting from infection of dwarf mistletoe (*Arceuthobium abietinum* Engelm. ex Munz) and a canker-

causing fungus (*Cytospora abietis* Sacc.) (Scharpf 1969). In estimating Ragged Percent (RPCT), raggedness resulting from one-sidedness and scattered branch death were combined, as both were expected to contribute to crown weakening, and thus to increased risk of death. The estimates are combined by estimating the percentage of the crown missing or dead because of one-sidedness (R^1). Then the percentage of crown raggedness because of scattered branch death (R_{df}) is estimated, and multiplied by the proportion of crown remaining: $P = (100-R^1)/100$. The two estimates are summed to obtain the combined estimate as expressed in the formula: $RPCT = R^1 + (P \times R_{df})$.

The effect of crown raggedness is illustrated *(fig. 2)*. Because both red firs at center were dominant with 50 percent live crowns, 3 and 50 were entered in the red fir equation for CCLS and CPCT, respectively. The tree on the right, however, had a pointed top (TCON = 0), and the top on the tree at the left was rounded (TCON = 1). More importantly, however, the crown of the tree on the right was one-sided with nearly 50 percent missing ($R^1 = 50$), and about 60 percent of the remainder dead or dying ($R_{df} = 60$). Combining these, Ragged Percent (RPCT) = 50 + (0.5 × 60) = 80 percent. The calculated probability of this tree's dying within 1 year (P_1) was 0.04 and within 5 years (P_5), 0.19. In other words, about 19 percent of a population of identical trees was expected to die within 5 years. Only about 30 percent of the crown of the tree on the left was ragged, however, because of branch death, primarily in the lower crown (RPCT = 30). The calculated probabilities were: $P_1 = 0.007$, and $P_5 = 0.03$; that is, only 3 percent of such trees were expected to die within 5 years.

The effect of variations in crown vigor on risk calculated for white firs was similar *(fig 3.)*. The tree in *figure 3A* had a vigorous crown with about 30 percent of the crown length occupied by branches oriented at, or above, the horizontal, so Branch Angle Percent (BANG) = 30. A few lower crown branches were dead or dying (CDEN = 2), and Ragged Percent (RPCT) was set at 10. Although living inner bark was not visible in the bark fissures at breast height (BFIS = 2), the 5-year risk was only 0.004. Branch Angle Percent for the tree in *figure 3B* was also 30 percent (BANG = 30). About 60 percent of the crown, however, was ragged because of branch die-back (CDEN = 2, RPCT = 60) and, although living inner bark was also not visible in the bark fissures at breast height (BFIS = 2), the 5-year risk was higher ($P_5 = 0.04$). The living crown in the tree in *figure 3C* was limited to several clumps of foliage apparently produced adventitiously after death of the original crown. Because none of the latter was living, Branch Angle Percent (BANG), by definition, was zero. At least 90 percent of the crown was dead (CDEN = 2, RPCT = 90), however, and although the bark fissuring was the same as the other trees (BFIS=2), the 5-year risk (P_5) was 0.35. If RPCT, estimated to the nearest 10 percent, had instead been set at 100, the P_5 obtained would be 0.49. Because of the obvious difference in crown vigor, P_5 in the tree in *figure 3A* (left) varied about 100-fold from that in the tree in *figure 3C*.

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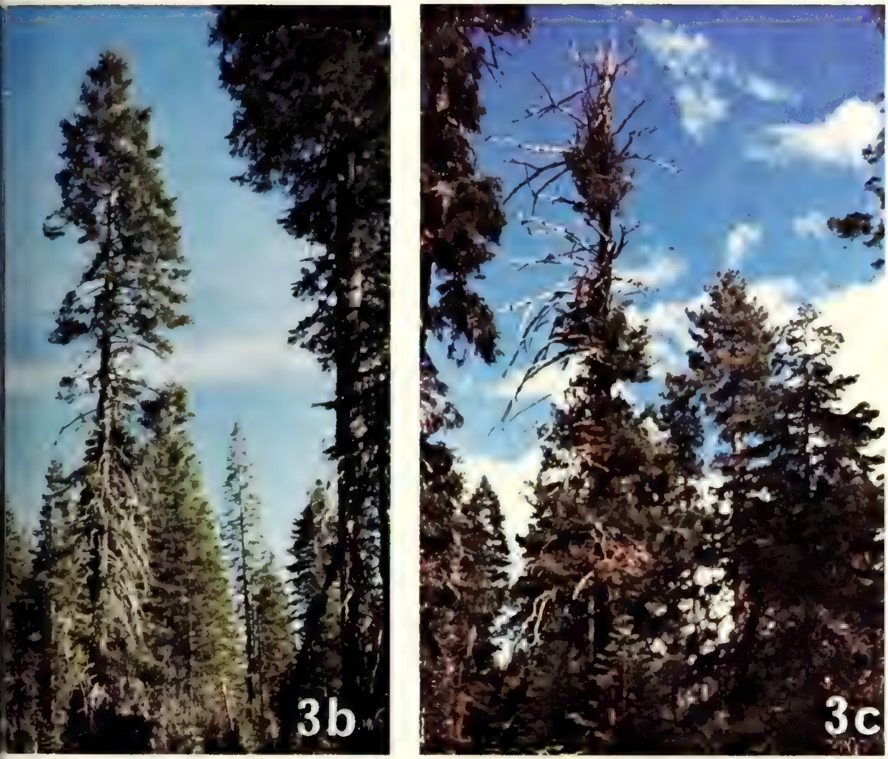

2 (upper left)—Effect of crown raggedness in mature red fir. Both trees had Live Crown Percent = tree on right had a more ragged crown (Ragged Percent = 80), and higher risk of death (19 within 5 years). Corresponding figures for tree on left were 30, and 5 percent, respectively.

Predictor	Rating Left	Rating Right
Class (CCLS)	Dominant	Dominant
own Percent (CPCT)	50	50
ndition (TCON)	Round	Pointed
Percent (RPCT)	30	80

3 (above)—Effect of crown raggedness in mature white fir. Primarily on the basis of variation in aggedness in the firs at centers of A, B, and C (Ragged Percent = 4, 60, and 90, respectively), the isk of death varied as follows: (A) 0.4 percent, (B) 4.0 percent, and (C) 35.0 percent.

Predictor	Rating A	Rating B	Rating C
angle percent (BANG)	30	30	0
lensity (CDEN)	Ragged (dead branches)	Ragged (dead branches)	Ragged (dead branches)
percent (RPCT)	5	60	90
sures (BFIS)	Dead	Dead	Dead

4 (lower left)—Effect of live crown length in mature red fir. Primarily because of its short crown own Percent = 10), fir at center of A has a 5-year probability of death of 0.16, while longer- tree at center of B (Live Crown Percent = 70) has a 5-year probability of death of only 0.006.

Predictor	Rating A	Rating B
lass (CCLS)	Dominant	Dominant
wn percent (CPCT)	10	70
dition (TCON)	Pointed	Round
percent (RPCT)	20	10

In red fir, the effect of another major risk predictor, Live Crown Percent (CPCT), is illustrated *(fig. 4)*. The fir in *figure 4A* (center) is dominant (CCLS = 3), but is short-crowned. If isolated lower branches are excluded, the living crown occupies only about 10 percent of the height of the tree, or Live Crown Percent (CPCT) = 10. The top is considerably rounded but a small pointed tip is present and so Top Condition is rated as pointed (TCON = 0). The short crown also includes a few dead and dying branches and Ragged Percent (RPCT) was set at 20. Primarily because of the short crown, however, this fir has a 16 percent chance of dying within 5 years. Fir in *figure 4B* is also dominant (CCLS = 3); however, it has a much longer crown: Live Crown Percent (CPCT) = 70. The top is round (TCON = 1), and a few dead and dying branches are present in the crown; Ragged Percent (RPCT) = 10. Primarily because of the longer crown, however, the risk of death is lower (P_5 = 0.006), and less than 1 percent of such trees are expected to die within 5 years.

AWARD-PENALTY POINT SYSTEMS

The risk equations were translated directly into point systems, thereby enabling calculation of risk by simple arithmetic *(tables 3,4)*. The relation-

Table 3—*Award-Penalty Risk System for mature red fir*

Crown Class	Award
Suppressed	0
Intermediate	2
Codominant	4
Dominant	6
Live Crown Percent (to nearest 10 percent of tree height)	
5 points for each 10 percent	———
Total Award	———
Top Condition	Penalty
Recent topkill	1
Ragged Percent (of crown missing, dead, and dying to nearest 10 percent)	
4 points for each 10 percent	———
Total Penalty	———
Risk Point Total	
a. Enter Total Award or Penalty (whichever larger)	———
b. Subtract smaller Total	———
c. Risk Point Total	———
Percent Mortality (within 5 years)	
a. Award equals or exceeds Penalty	0 to 20 percent
b. Penalty exceeds Award	

Points	Percent	Points	Percent
1 to 4	21 to 30	15 to 17	60 to 70
5 to 8	30 to 40	18 to 21	70 to 80
9 to 11	40 to 50	22 to 25	80 to 90
12 to 14	50 to 60	26+	90+

hips between risk and its predictors, as expressed in the equations, were maintained in the point systems so that little retraining would be required in hifting from one method of predicting risk to the other. In the point systems, he tree is awarded points on the basis of estimates of predictors with positive oefficients in the equations, and penalized points on the basis of the state of redictors with negative coefficients. For convenience of the user, it was esirable to have the points awarded or penalized in whole numbers as small s possible. This was done by rounding off each coefficient, multiplying it y the appropriate estimate of its predictor variable, and then multiplying the roduct by a factor of 10. The results from screening the tree characteristics or their association with tree death indicated that, for some of the predictors, ertain ratings could be omitted or combined with others, with little loss in redictive power. Where possible, this was done to simplify the point ystems.

By using the risk equations, the difference between Award and Penalty oint Totals—the Risk Point Total—was translated into the percentage of

Table 4—*Award-Penalty Risk System for mature white fir*

Branch Angle Percent	Award
(to nearest 10 percent of crown length)	
3 points for each 10 percent	—
Total Award	—
Crown Density	**Penalty**
Dense	0
Ragged, due to:	
a. One-sidedness	1
b. Dead and dying branches	2
c. Combination a and b	2
Thin	3
Ragged Percent (of crown missing, dead and dying to nearest 10 percent)	
5 points for each 10 percent	—
Bark Fissures	
a. Living inner bark visible	0
b. No living inner bark visible	28
Total Penalty	—
Risk Point Total	
a. Enter Total Award or Penalty (whichever larger)	
b. Subtract smaller Total	—
c. Risk Point Total	—
Percent Mortality (within 5 years)	
a. Award equals or exceeds Penalty	0 to .03 percent
b. Penalty exceeds Award	

Points	*Percent*	*Points*	*Percent*
1 to 50	.03 to 5	71 to 74	30 to 40
51 to 57	5 to 10	75 to 77	40 to 50
58 to 65	10 to 20	78 to 80	50 to 60
66 to 70	20 to 30	80+	60+

trees expected to die within 5 years. The range of possible Risk Point Totals was calculated from the minimum and maximum Award and Penalty Point Totals allowed by the system. All Risk Point Totals possible within this range were divided by 10 to convert them back into values appropriate for substitution in the equations in place of the vector of predictor variables, and probabilities of death were calculated for the entire range of prediction. During the calculations it was noted that, if the Award Point Total equaled or exceeded the Penalty Point Total, the predicted probabilities were all so low that they were placed in a single broad interval as no further breakdown was needed. When the Penalty Point Total exceeded the Award Point Total, the excess or Risk Point Total and the corresponding probability were also tabulated, for convenience, by intervals. These intervals were considered to be adequate for most risk predictions. For 85 percent of the red firs and 90 percent of the white firs, the probabilities obtained from the equations fell within the intervals predicted by the point systems when large samples of trees were rated by both methods. The probabilities were also plotted as a function of the Risk Point Total *(fig. 5)* so that more exact risk predictions could be obtained, if this was desired. As an aid to interpretation, both the tabulated and graphed probabilities were expressed as the percentage of a hypothetical population of identical trees expected to die within 5 years.

The differences between the two functions depicted in *figure 5* reflect differences in the observed mortality rates of the two species on the plots. Overall, mortality rates for white fir (0.3 percent of the estimated total number of mature white firs on the plots, or 0.14 trees/acre) were much lower than the corresponding rates for red firs (0.9 percent or 0.21 trees/acre). At least some of this difference was attributed to the greater amount of crown raggedness caused by heavier infections of dwarf mistletoe and *Cytospora* in the red firs as 53 percent of the trees had crowns with at least some scattered branch dieback attributed to these agents, and frequently more than one-half the foliage was dead or dying. In contrast, although 42.2 percent of the white firs sampled were similarly afflicted, only rarely was more than 20 percent of the foliage killed. Consequently, the highest 5-year probabilities obtained for white fir were just over 40 percent, while those calculated for red fir approach 100 percent.

Use of these point systems to risk-rate trees is described in the *Appendix*.

MORTALITY AGENTS

Subcortical examination of the dead trees on the plots indicated that virtually the same complex of insects and diseases was the proximal cause of death in both white and red firs. The incidence of insects and diseases found beneath the bark in the lower boles of the dead trees is summarized in *table 5*. No statistical comparisons were made because of the limited number of trees sampled. (The importance of crown-weakening agents such as dwarf mistletoe and *Cytospora* cankers in predisposing these firs to death has been

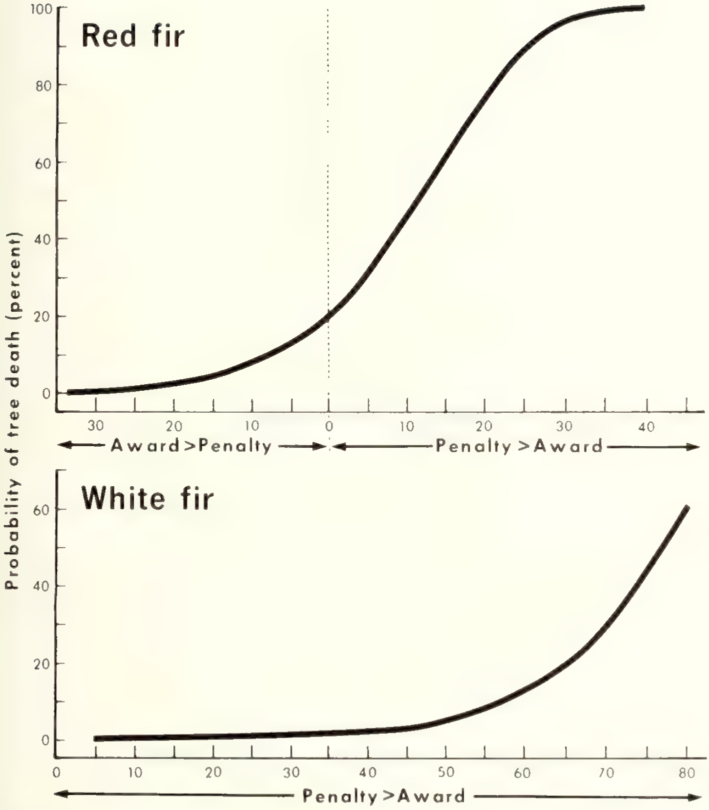

Figure 5—Percentage of mature firs expected to die within 5 years as a function of the Risk Point Total, obtained by comparison of the award, penalty point totals.

discussed above.) Overall, results from red fir and white fir were similar. More than two-thirds of the trees evidenced subcortical beetles, but no root decay fungi. The latter, without the former, were found in only 2 to 3 percent of the trees. Both agents were found in 10 percent of the firs, but neither agent was found in nearly 20 percent of the white firs, and 10 percent of the red firs. The relatively low incidence of observed root diseases, either by themselves or in combination with subcortical beetles, was probably because of the difficulty of diagnosing their presence on the basis of chopping into the trunk only at soil level. Surveys using partial excavation of root systems reported that more than 80 percent of dead white firs in the Central Sierra Nevada (Cobb and others 1974), and even higher percentages of dead white firs and Shasta red firs in southern Oregon (Lane and Goheen 1979), had root diseases.

Eighty percent of the red firs, and more than 50 percent of the white firs, had been infested by cambial-mining round- and flat-headed fir borers

Finally, cutting experiments must be made, in which fir stands are marked and cut using the risk systems, and subsequent mortality rates are compared with those in similar, uncut stands. If lower fir mortality results from logging stands on this basis, the risk systems can be considered to be verified, and should contribute to the long-term management of California's true firs.

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APPENDIX — USERS GUIDE: AWARD-PENALTY POINT SYSTEMS

The Risk-Rating Systems . . .

- Predict the probability of individual tree death within 5 years as a result of natural causes—insects, diseases, weather, or other.
- Apply only to mature firs at least 10 inches (25.4 cm) d.b.h., growing in mature stands with the original overstory at least partially intact.
- Are most applicable to the region sampled in developing them; outside the region sampled they should be used only tentatively, pending results of studies intended to verify or modify them for use in these other areas. These risk-rating systems are applicable to the southern Cascade Mountains from the vicinity of Lassen Peak, north to Mt. Shasta, and the eastern Siskiyou Mountains near the Oregon border. The red fir system is also applicable to Shasta red fir (var. *shastensis* Lemm.) growing within this region. These systems should apply also to firs in the Warner Mountains and nearby ranges in northeastern California, in the Salmon-Trinity and Marble Mountains in northwest California, and in the Sierra Nevada north of Lake Tahoe.

Award-Penalty Point Systems

A tree is awarded points on the basis of estimates of predictors that are negatively correlated with risk; a tree is penalized points on the basis of estimates of predictors that are positively correlated with risk.

Risk predictors selected for red fir are: *Crown Class, Live Crown Percent, Top Condition,* and *Ragged Percent.*

Risk predictors selected for white fir are: *Branch Angle Percent, Crown Density, Ragged Percent,* and *Bark Fissures.*

Estimating Predictors

Several of the predictors are used in both the red fir and white fir systems and, because estimation procedures are identical, definitions of these predictors are common to both systems:

Crown Class—the estimate of the tree's crown relative to those of adjacent trees. Crown classes are those ordinarily used by foresters:

Dominant—considerably taller than adjacent trees or isolated from competitors for light.

Codominant—about the same height as adjacent trees, with sides of crown receiving only limited light.

Intermediate—crown well beneath taller trees but receiving limited direct light, often only at midday.

Suppressed—completely overtopped by nearby trees, receiving only diffuse light.

Live Crown Percent—percentage of a tree's total height occupied by live crown, estimated to nearest 10 percent. The live crown is defined as extending from the tree's top, regardless of whether live or dead (topkill, spiketop), to the lower limit of the living crown. If top is broken off, live crown extends downward from point of breakage. Live crown includes all internal dead branches above lower limit of live crown (see Ragged Percent definition).

Setting lower limit of live crown:

- Exclude single, isolated lower branches
- For one-sided crowns, use longer side.
- If branches droop, use horizontal projection of branch tips onto bole.
- Exclude epicormic foliage unless judged to "contribute significantly to sustenance of tree." Note: This is subjective and needs more research.

Crown Density—categorize crown as to shape and condition of foliage and branches.

Dense—foliage with needles normal in length, number, and color. Dead, dying, off-color or thin foliage absent or, if present, amounting to less than 5 percent of total crown.

Ragged—localized reduction in foliage density because of: One-sidedness—one side of crown or portion thereof missing because of shading or crown injury resulting from falling neighbor tree (crown-raking); dead and/or dying branches or twigs, either scattered throughout crown, or concentrated in top (topkill, spiketop) or other section of crown (ignore broken, missing tops); or, combination of one-sidedness and dead-dying branches or twigs.

Thin—crown uniformly sparser than normal from reduced number and length of needles.

Ragged Percent (RPCT)—combined percentage of crown missing, and/or dead or dying, estimated to nearest 10 percent of crown. Include missing portions of crown above lower limit of live crown, whether contributing to one-sidedness or not. Include portions of crown that are dead or missing because of topkilling, regardless of whether topkill is recent (dead foliage retained) or older (dead foliage missing as in spiketop).

In the red fir risk system, variation in estimates of Live Crown Percent and Ragged Percent tend to compensate for one another in the calculation of risk for any individual tree. Including isolated, lower living branches in the live crown, while leading to higher estimates to Live Crown Percent will be compensated for by resultant increases in estimates of Ragged Percent. Trials indicate that the same, or closely similar risks will be obtained regardless of such differences in the height at which the observer sets the lower limit of the live crown. Branch Angle Percent and Ragged Percent similarly compensate for one another in the white fir system. Criteria for setting lower limit of live crown can be found in discussion of Live Crown Percent.

In crowns that are ragged because of one-sidedness and scattered branch death, it is frequently convenient to estimate the combined Ragged Percent as follows: 1) Estimate the percentage of crown missing because of the one-sidedness (R^1); 2) then estimate the raggedness because of dead and dying (flagged) branches as a percentage of the crown still present (R_{df}). R_{df} is then multiplied by the proportion of the entire crown still present (P) to obtain the contribution of the scattered branch die-back to the combined estimate of raggedness for the entire crown. The two estimates are then summed to obtain RPCT. The process is expressed by the formula: $RPCT = R^1 + (P \times R_{df})$.

Branch Angle Percent—Percentage of the total length of live crown with upswept to horizontal branches estimated to nearest 10 percent of crown. Branch tips should equal or exceed height at which branches join with bole. Criteria for setting lower limit of live crown can be found in discussion of Live Crown Percent.

Top Condition—For use in Award-Penalty System, only if the tree is recently topkilled; recent topkills retain faded foliage. Ignore killed tops

Appendix Table 1—*Award-Penalty Risk System for mature red fir*

Crown Class	Award
Suppressed	0
Intermediate	2
Codominant	4
Dominant	6
Live Crown Percent (to nearest 10 percent of tree height)	
5 points for each 10 percent	____
Total Award	____
Top Condition	Penalty
Recent topkill	1
Ragged Percent (of crown missing, dead, and dying to nearest 10 percent)	
4 points for each 10 percent	____
Total Penalty	____
Risk Point Total	
a. Enter Total Award or Penalty (whichever larger)	____
b. Subtract smaller Total	____
c. Risk Point Total	____
Percent Mortality (within 5 years)	
a. Award equals or exceeds Penalty	0 to 20 percent
b. Penalty exceeds Award	

Points	Percent	Points	Percent
1 to 4	21 to 30	15 to 17	60 to 70
5 to 8	30 to 40	18 to 21	70 to 80
9 to 11	40 to 50	22 to 25	80 to 90
12 to 14	50 to 60	26+	90+

occupying less than 5 percent of the length of the live crown (that is, tip dieback).

Bark Fissures—Record as live or dead depending upon whether or not light-colored living bark is visible in most of the fissures in the dead bark when the trunk is viewed at breast height from at least 4 feet away. Ignore callous or scar tissue associated with healed cracks of injury.

Examples

Using the Point Systems, some examples of the use of the Award-Penalty Point Systems to predict risk are illustrated in *appendix figures 1 and 2.*

The red fir in *appendix figure 1A* is dominant, for which it is awarded 6 points under Crown Class *(app. table 1.)* About 60 percent of its height is in live crown, thus the Live Crown Percent award is 6 × 5, or 30 points. The Total Award is then 36 points. The top is living and so is not penalized. However, the lower crown has scattered branch dieback, amounting to about 60 percent of the entire crown, and so is penalized 6 × 4, or 24 points, which is the Total Penalty for this tree. Reference to the bottom of the table indicates that, because Award exceeds Penalty, from 0 to 20 percent of such trees are expected to die within 5 years.

In contrast, the red fir (center) in *appendix figure 1B* is dominant (6 points) and has a Live Crown Percent of 50 (25 points), summing to a Total Award of 31 points. The top is live, and so is not penalized. The crown is ragged,

Appendix Figure 1 (top right)—Risk-rating mature red firs using the Award-Point System. Both firs (central trees in A and B) were dominant and had sim crown percentages and so were given similar Award-Point Totals. Because of crown raggedness, however, tree in B had both a higher Penalty-Point Tota higher risk of death within 5 years (30 percent), than tree in A (6 percent).

Predictor	Rating A	Rating B
Crown Class	Dominant	Dominant
Live Crown Percent	60	50
Top Condition	Live	Live
Ragged Percent	60	90

Appendix Figure 2 (bottom right)—Risk-rating mature white firs using the Penalty Point System. Dominant white fir in A (center) had a higher Point because of horizontal to upturned branches in the upper crown, and a lower P Point total because of less crown raggedness, than the suppressed fir in B completely sagging, ragged crown. The 5-year risk of death for tree in A is near compared with the 5-year risk of death for tree in B, which is 43 percent.

Predictor	Rating A	Rating B
Branch Angle Percent	20	0
Crown Density	Ragged (dead branches)	Ragged (one-sided and dead, dying branches)
Ragged Percent	20	90
Bark Fissures	Dead	Dead


1b


2b

Appendix Table 2—*Award-Penalty Risk System for mature white fir*

Branch Angle Percent	Award
(to nearest 10 percent of crown length)	
3 points for each 10 percent	______
Total Award	______
Crown Density	**Penalty**
Dense	0
Ragged, due to:	
a. One-sidedness	1
b. Dead and dying branches	2
c. Combination a and b	2
Thin	3
Ragged Percent (of crown missing, dead and dying to nearest 10 percent)	
5 points for each 10 percent	______
Bark Fissures	
a. Living inner bark visible	0
b. No living inner bark visible	28
Total Penalty	______
Risk Point Total	
a. Enter Total Award or Penalty (whichever larger)	______
b. Subtract smaller Total	______
c. Risk Point Total	______

Percent Mortality (within 5 years)

a. Award equals or exceeds Penalty .... 0 to .03 percent

b. Penalty exceeds Award

Points	*Percent*	*Points*	*Percent*
1 to 50	.03 to 5	71 to 74	30 to 40
51 to 57	5 to 10	75 to 77	40 to 50
58 to 65	10 to 20	78 to 80	50 to 60
66 to 70	20 to 30	80+	60+

however; 40 percent is missing on the near side ($R^1 = 40$), and in the remaining 0.6 of the crown about 90 percent of the branches are dead or fading ($R_{df} = 90$). Combining these, RPCT $= 40 + (0.6 \times 90) = 40 + 54 = 94$, which rounded to the nearest 10 percent, is equal to 90 percent. The Total Penalty is $9 \times 4 = 36$ points, which exceeds Total Award by 5 points. The 5-year risk falls into the interval of 30 to 40 percent. Results of our study suggest that 30 to 40 percent of such trees can be expected to die within 5 years.

The white fir (center) in *appendix figure 2A* has a long crown, especially if the lower limit is set at the lowest clump of living foliage on left. In this instance, only the upper 20 percent of the length of the crown is occupied by horizontal or upturned branches and, consulting *appendix table 2,* the tree is awarded 2×3, or 6 points under Branch Angle Percent. Interpreted this way, the crown is ragged because of included dead branches in the lower

crown, and so is penalized 2 points under Crown Density. The dead and missing branches comprise about 20 percent of the crown, for which the tree is penalized an additional 2×5, or 10 points under Ragged Percent. Living inner bark was not visible in the fissures between the plates of dead, outer bark when the bole was examined at breast height. The tree, therefore, was further penalized 28 points under Bark Fissures. The total Penalty (40) exceeded the Total Award (6), by 34 points. The tabulated 5-year risk is low, somewhere in the interval of 0.03 to 5 percent. Had the scattered living branches in the lower crown been ignored when setting the lower limit of the live crown, the tree would have about 50 percent of the height in living crown. In this instance, horizontal or upturned branches occupy 30 percent of the crown, and the tree is awarded 2×3, or 9 points under Branch Angle Percent. Because the lower ragged portion of the crown is now excluded from consideration, the crown is rated as dense under Crown Density, with a Ragged Percent of zero. Bark Fissures are unchanged, rated as dead. Using this interpretation, the Total Penalty (28) exceeds the Total Award (9) by 19 points. The resulting risk estimate varies little, however, from that obtained by means of the first crown interpretation.

The suppressed white fir in *appendix figure 2B* can also be risk-rated by the system, if desired. None of the branches are horizontal or upturned, therefore, Branch Angle Percent is zero and the Total Award is also zero points. Under Crown Density, the crown is ragged because of a combination of one-sidedness, and dead and dying branches (2-point penalty). The combined Ragged Percent is estimated at 90 percent ($50 + 0.5 \times 80$) and for this the tree is penalized another 45 (9×5) points. The Bark Fissures are dead at breast height (28 penalty points), thus the Risk Point Total sums to 75 penalty points. This penalty corresponds to a tabulated risk of 40 to 50 percent. Our study suggests that 40 to 50 percent of such trees are expected to die within 5 years.

Appendix Table 1 —*Award-Penalty Risk System for mature red fir*

Crown Class	Award
Suppressed	0
Intermediate	2
Codominant	4
Dominant	6
Live Crown Percent (to nearest 10 percent of tree height)	
5 points for each 10 percent	_____
Total Award	_____
Top Condition	Penalty
Recent topkill	1
Ragged Percent (of crown missing, dead, and dying to nearest 10 percent)	
4 points for each 10 percent	_____
Total Penalty	_____
Risk Point Total	
a. Enter Total Award or Penalty (whichever larger)	_____
b. Subtract smaller Total	_____
c. Risk Point Total	_____

Percent Mortality (within 5 years)

a. Award equals or exceeds Penalty .... 0 to 20 percent

b. Penalty exceeds Award

Points	Percent	Points	Percent
1 to 4	21 to 30	15 to 17	60 to 70
5 to 8	30 to 40	18 to 21	70 to 80
9 to 11	40 to 50	22 to 25	80 to 90
12 to 14	50 to 60	26+	90+

Ferrell, George T.

1980. **Risk-rating systems for mature red fir and white fir in northern California.** Gen. Tec Rep. PSW-39, 29 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U. Dep. Agric., Berkeley, Calif.

On the basis of crown and bole characteristics, risk-rating systems to predict the probability thai tree will die within 5 years were developed for mature red fir and white fir in northern California. T systems apply to firs at least 10 inches (25.4 cm) in diameter-at-breast-height (d.b.h.), growing mature stands, with the original overstory at least partially intact. From 1975 to 1977, 1012 red firs (8 live, 161 dead) and 2571 white firs (2430 live, 141 dead) were examined in virgin and cutover stand Tree characteristics were selected and used as predictor variables in regression equations. The ri equations were then translated into Award-Penalty Point Systems for field use. A tree is awarded poir on the basis of ratings of some characteristics, and penalized points on the basis of ratings of others. T difference between the Award and Penalty Point Totals—the Risk Point Total—is the value used predict a tree's death within 5 years. This report describes studies designed to develop, test, and exte the risk-rating systems. Properly used, these systems should contribute to the sound, long-tei management of California's true firs.

Retrieval Terms: Abies concolor, Abies magnifica, California, mortality, risk rating, bark bori insects.

Appendix Table 2—*Award-Penalty Risk System for mature white fir*

Branch Angle Percent (to nearest 10 percent of crown length)	**Award**
3 points for each 10 percent	______
Total Award	______
Crown Density	**Penalty**
Dense	0
Ragged, due to:	
a. One-sidedness	1
b. Dead and dying branches	2
c. Combination a and b	2
Thin	3
Ragged Percent (of crown missing, dead and dying to nearest 10 percent)	
5 points for each 10 percent	______
Bark Fissures	
a. Living inner bark visible	0
b. No living inner bark visible	28
Total Penalty	______
Risk Point Total	
a. Enter Total Award or Penalty (whichever larger)	______
b. Subtract smaller Total	______
c. Risk Point Total	______
Percent Mortality (within 5 years)	
a. Award equals or exceeds Penalty	0 to .03 percent
b. Penalty exceeds Award	

Points	*Percent*	*Points*	*Percent*
1 to 50	.03 to 5	71 to 74	30 to 40
51 to 57	5 to 10	75 to 77	40 to 50
58 to 65	10 to 20	78 to 80	50 to 60
66 to 70	20 to 30	80+	60+

United States
Department of
Agriculture

Forest Service

**Pacific Southwest
Forest and Range
Experiment Station**

General Technical
Report PSW-40

FIRESCOPE:
a new concept in multiagency fire suppression coordination

Richard A. Chase

The Author

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PREFACE

For a 2-week period in fall 1970, a continuing siege of major wildfires over the chaparral region of southern California severely taxed the capabilities of the region's fire protection agencies and caused major damage to structures and wildland resources. As a result, in 1971, Congress directed its attention to the southern California fire problem. During the second session of the 92d Congress, a subcommittee of the House of Representatives, Committee on Appropriations, recommended an appropriation of "$900,000 to strengthen fire command and control systems research at Riverside, California, and Fort Collins, Colorado." The House subcommittee further recommended: "At Riverside, research will concentrate on developing advanced airborne fire intelligence methods for detecting and mapping fires, including real time telemetry of information and display at fire command control centers..."

With the subsequent appropriation of funds, a research, development and application (RD&A) program was established at the Pacific Southwest Forest and Range Experiment Station's Forest Fire Laboratory, Riverside, California. In response to the Congressional directive, research was to identify the most productive study areas and approaches for the RD&A program. Analysis of the problem was carried out jointly by Forest Service researchers and principal southern California fire agencies. This analysis quickly showed that the solution must involve a major systems design that would necessarily address not only advanced airborne fire intelligence methods, but fire information systems generally and their effective utilization in planning and coordinating action on both single- and multiple-agency fires or similar emergencies. The program charter was prepared accordingly and formally approved in March 1973.

The intent of the total program was to design and provide the procurement, testing, and implementation of an operational fire suppression coordination system, assuming that implementation funding would become available in an orderly and timely manner as the program proceeded. Such funding, however, did not materialize within the 5-year R&D phase of the program. The research product was therefore redefined in June 1976 as a series of performance specifications for recommended subsystems, and implementation was delayed. The specification reports, which form the basis of the system descriptions herein, are listed in the footnotes. These reports were prepared by the Station and contractors.

In October 1975, in preparation for the implementation phase, leadership responsibility began to shift from the Pacific Southwest Station to State and Private Forestry, California (now Pacific Southwest) Region of the Forest Service. Research and development work required to complete the design and support implementation was assigned to a research work unit.

The major product of this complex team effort involving Forest Service researchers and land managers, cooperating fire agencies, and contractors was FIRESCOPE (*FI*refighting *RE*sources of *S*outhern *C*alifornia *O*rganized for *P*otential *E*mergencies—a new concept and system in multiagency fire suppression coordination).

The principal researchers and their contributions:

- Stanley N. Hirsch, program manager (1972-1975)—general program management.
- Richard A. Chase, assistant program manager (1972-1975); Research Work Unit Leader (1975-1978)—program coordination, overall system concept design and development.
- Randall J. Van Gelder, operations research analyst—information management system design and development.
- John W. Warren, electronic engineer, communication system, infrared telemetry, weather telemetry design.
- Kelly Mason, electronic engineer, communication system, mobile communication unit, and weather telemetry network design.
- Romain M. Mees, operations research analyst—information services development.

Research Work Units that furnished technical support:

- Forest Fire Meteorology (PSW-2108), Pacific Southwest Forest and Range Experiment Station, Riverside, Calif.
- Management of Chaparral and Related Ecosystems (PSW-16), Pacific Southwest Station, Riverside, Calif.
- Fire Fundamentals (INT-2103), Intermountain Forest and Range Experiment Station, Missoula, Mont.

Program support and technical advice was provided by personnel from these agencies:

- California Department of Forestry
- California Office of Emergency Services
- Los Angeles City Fire Department
- Los Angeles County Fire Department
- Santa Barbara County Fire Department
- California Region, Forest Service, U.S. Department of Agriculture
- Ventura County Fire Department

Principal contractors to the program were:

- The Aerospace Corporation, El Segundo, Calif.
- Mission Research Corporation, Santa Barbara, Calif.
- System Development Corporation, Santa Monica, Calif.
- Stanford Research Institute, Palo Alto, Calif.
- University of California, Berkeley, Calif.

The recommendations, criteria, and descriptions outlined in this report resulted from an iterative process involving cooperators, researchers, land managers, and contractors. In addition, the implementation program now underway and directed by Robert L. Irwin, State and Private Forestry, Pacific Southwest Region, Forest Service, was begun 18 months before the research effort was terminated. Therefore, some of the final design recommendations included changes related to evaluation, testing, and modification in the implementation program. This iterative process also resulted in the rejection of parts or all of the contractor reports. These reports, which have been made available to cooperators, may become valuable reference documents, however, for any future work designed to improve and strengthen FIRESCOPE.

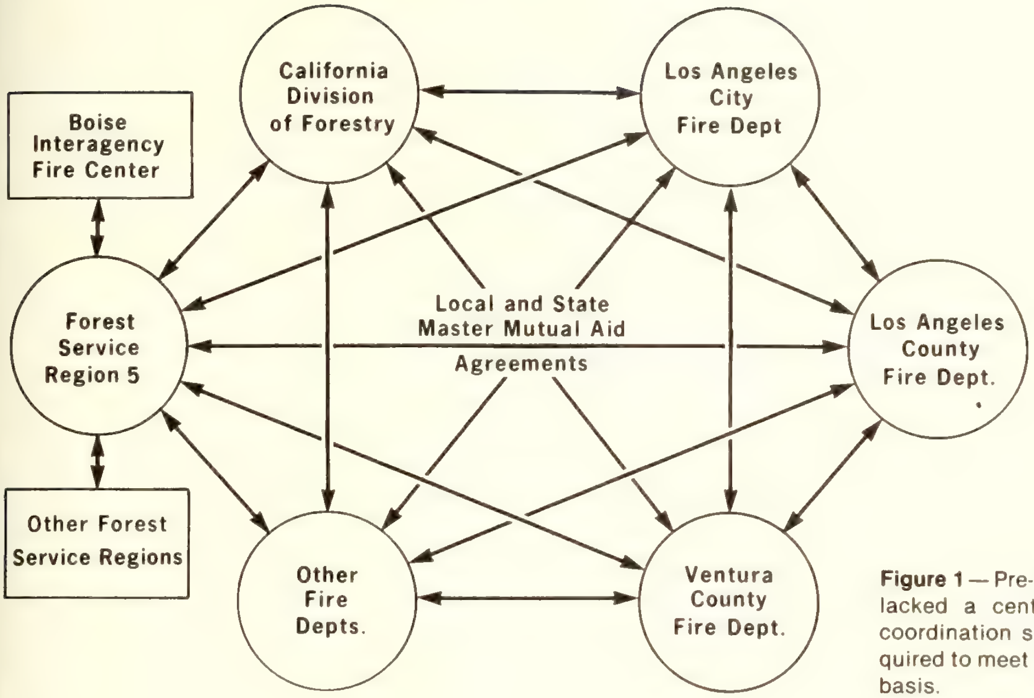


Figure 1 — Pre-FIRESCOPE coordination lacked a centralized information and coordination source. Agencies were required to meet this need on an individual basis.

During the 13-day period from September 22 to October 4, 1970, 17 major wildland fires driven by ›t, dry winds burned one-half million acres in southern alifornia, severely damaging valuable watershed and her resources, destroying nearly 700 structures, and king 16 lives (Phillips 1971).

Cooperation between Federal, State, County, and local re services in this full-scale emergency was sound. All gencies recognized, however, that a number of problems gnificantly hampered the effectiveness of this ooperation (Task Force on California's Wildland Fire roblem 1972). Most apparent was the lack of a central- ed information source from which to obtain accurate,)-to-the-minute facts about the fast-changing fire uation regionwide and an inability to carry out central- ed planning. This fact made it difficult—sometimes npossible—to establish rational priorities in allocating arce fire suppression resources and coordinating dividual agency requests for aid (*fig. 1*). Considerable fficulty was encountered in establishing and maintaining mmunications between the various agency units on the firelines because of the high volume of radio traffic and the many radio frequencies involved. Confusion also existed between agencies because of nonuniformity in terminology, wildland fire suppression organization structure, and procedures (Chase 1977a).

As a result, the major agencies involved in wildland fire protection in southern California agreed to cooperate in a research and development program that would address the problems of the 1970 situation. The participating agencies included the Forest Service of the U.S. Department of Agriculture, California Department of Forestry, California Office of Emergency Services, and the fire departments of Los Angeles City and the Counties of Los Angeles, Santa Barbara, and Ventura. The program was initiated in 1972 under the direction of the Pacific Southwest Forest and Range Experiment Station, with subsequent design participation by the seven "partner" protection agencies. Thus marked the inception of *FIRESCOPE—FI*refighting *RE*sources of *S*outhern *C*alifornia *O*rganized for *P*otential *E*mergencies.

DESIGN PROCESS

FIRESCOPE probably represents the first practical application of systems design to a major, complex wildland fire management operational problem. The systems approach to fire management requires that the fire problem and potential solutions be addressed as a single entity—the sum of all subsystems and their interrelationships (Maloney and Potter 1974, Simard 1977). The design aims to maximize effectiveness of the total system, rather than its individual components. This point is important if subsequent attempts are made to implement only selected parts of the design, for expected operating benefits may not fully materialize.

The intent of the research design effort was to "make a quantum jump in the capability of southern California wildland fire protection agencies to effectively coordinate interagency action and to allocate suppression resources in dynamic, multiple-fire situations."[1] The following criteria directed the aim of the system design:

- Identify state-of-the-art technology acceptable for 1980 implementation.
- Achieve design consensus between partner agencies while remaining responsive to individual organizational, political, legal, and financial needs and constraints.
- Assert cost effectiveness.
- Complement daily operational and equipment needs of each partner agency to the fullest extent possible.
- Encourage investments that favored initial capital outlay and minimized subsequent operation and maintenance costs. Such investment strategy was based on the observed problem of agencies to secure increased annual operating funds versus the one-time capital investment. (This issue became even more critical with the 1978 passage of California's Proposition 13, which significantly affected local operating budgets.)
- Implement system components in prototype, whenever possible, as soon as the design was completed to enable research evaluation and appropriate operational testing.

Generally, these goals were successfully met and the design presented here was responsive to them. Unfortunately, however, partner input and consensus remained an elusive goal during the life of the program. Expectations were not met relating to (1) the role of individual agencies in defining system performance standards and requirements and (2) anticipated differences resolving in a consensus position. The design therefore represents research's best judgment of a system that most closely approximates the program purpose while remaining responsive to collective agency needs. Such sensitivity coupled with a critical, systematic analysis and rational solutions advance the design toward eventual acceptance and implementation. The system is *not* presented as fully endorsed in all of its components by all parties involved. All participating agencies have, however, formally agreed to the basic concepts fundamental to the general system design.[2]

The level of design development was greatly affected by two factors: lack of agency consensus on a number of important operational details—such as the communication system configuration and data processing system standards—and concurrent uncertainty over the amount and timing of system procurement and operational funding. Based on these contingencies, reasons of efficiency determined that some subsystems not be developed beyond performance specifications. Procurement specifications were implemented, however, for those subsystems that required development of prototype hardware or software for research design evaluation. Principal research documents therefore represent various levels of design completion, but all minimally contain system performance specifications.

Preliminary assessment of estimated protection costs plus wildfire losses associated with the implementation of the recommended system design showed potential savings in excess of 15 percent of the current annual average.[3]

OPERATIONAL CONCEPTS

The basic operational concept of the FIRESCOPE system calls for timely commitment of adequate multiagency resources, operating under common procedures and organizational structure, to all incidents which exceed, or threaten to exceed, the capability of any single fire protection agency.[4] Though primarily oriented toward suburban

[1] Forest Service, U.S. Department of Agriculture. 1973. FIRESCOPE RD&A program charter, March 26, 1973. (Unpublished document on file at Forest Fire Laboratory, Pacific Southwest Forest and Range Experiment Station, Riverside, Calif.)

[2] Forest Service, U.S. Department of Agriculture. 1974. FIRESCOPE multiagency coordination system development agreement. June 26, 1974. (Unpublished document on file at Forest Fire Laboratory, Pacific Southwest Forest and Range Experiment Station, Riverside, Calif.)

[3] Stanford Research Institute. 1974. An economic evaluation of multiagency communication and coordination systems for southern California. (Unpublished report on file at Forest Fire Laboratory, Pacific Southwest Forest and Range Experiment Station, Riverside, Calif.)

[4] Mission Research Corporation and System Development Corporation. 1974. A conceptual definition of a wildland fire management regional coordination system. (Unpublished report on file at Forest Fire Laboratory, Pacific Southwest Forest and Range Experiment Station, Riverside, Calif.)

ldland interface fire problems, the system also has the pability to provide appropriate support to agencies sponsible for other types of incidents, such as urban fires rescues.[5]

The FIRESCOPE concept consists of the interrelation- ip of two independent systems: the Incident Command stem (ICS), to provide more effective onsite utilization d management of resources; and the Multiagency Coor- nation System (MACS), to facilitate efficient allocation of sources from all involved Federal, State, and local encies to incidents on a regional basis (principally the ven-county area in southern California between the ocean d the desert) (*fig. 2*).

ıcident Command System

At the incident level, the Incident Command System CS) provides:

Uniform terminology, procedures, and incident organi- zation structure required to ensure effective coordinated action when two or more agencies are involved in a combined effort.

Improved communications, particularly between units of different agencies.

Modern data collection, transmission, and processing systems to provide timely and accurate weather, fire pe- rimeter, suppression and rescue resource status, and similar information needed for incident planning and management.

The Incident Command System can accommodate a riety of incident types, sizes, and operational environ- ents. Particular functions and organizational elements e activated only at the time and to the extent dictated by erational requirements of each specific incident. Coor- nation of such an effort presumes that all agencies adopt iform terminology (and procedures, to the extent com- tible with operational requirements of individual encies) for day-to-day use, as well as minimal uniform ining and qualification standards for personnel poten- lly assigned to multiagency incidents.

Jurisdictional command responsibility and authority are t compromised. Unless there is express agreement to the ntrary, each agency retains its legal responsibility within jurisdiction and is assumed to maintain full command thority within that jurisdiction at all times.

Equipment and personnel from assisting agencies are nerally grouped under the command of their own pervisory personnel who receive direction from the sponsible agency through command channels.

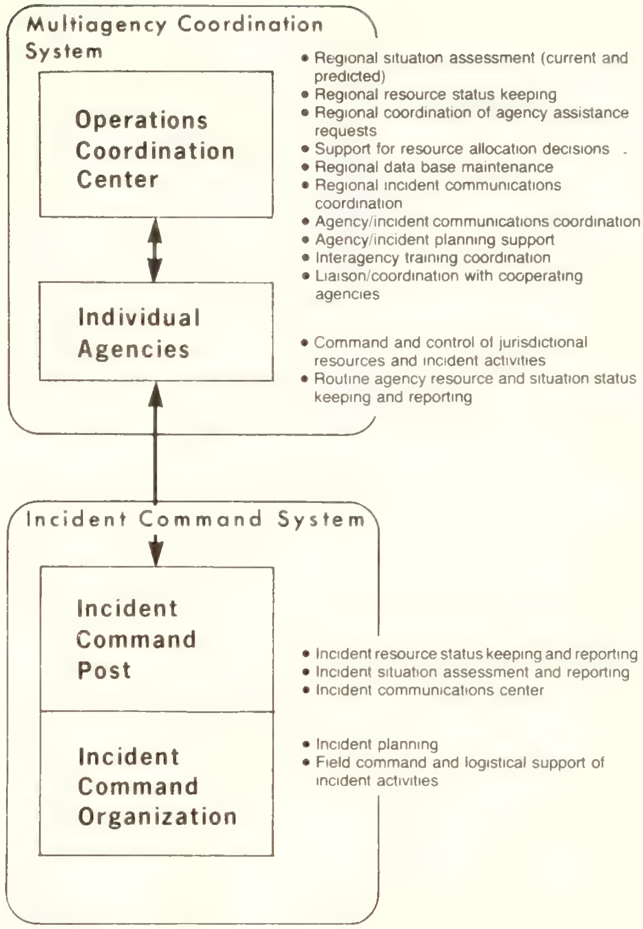


Figure 2—FIRESCOPE interrelates two independent systems, the Multiagency Coordination System (MACS) and the Incident Command System (ICS).

On multijurisdiction incidents, unless otherwise agreed, each agency exercises full command authority within its jurisdiction through its own Incident Commander and appropriate subordinate command positions. Where such is the case, overall command, logistics, and planning functions between jurisdictions are coordinated through the multiagency Incident Command Post (ICP). The joint ICP is staffed with appropriate operational personnel from each agency, as necessary, to plan and execute fully coordinated operations for the entire incident area.

The major elements of the ICS, namely, common terminology, uniform organizational structure, and uniform procedures for incident operations, have been tested and adopted by all partner agencies, and are currently being implemented in the FIRESCOPE area.

Multiagency Coordination System

The Multiagency Coordination System (MACS) is designed to perform regional information management, situation assessment, resource coordination, and other

[5] lission Research Corporation and System Development Corporation. 13. A discussion of FIRESCOPE system functions and enabling p cies. (Unpublished report on file at Forest Fire Laboratory, Pacific S thwest Forest and Range Experiment Station, Riverside, Calif.)

services as appropriate, to support existing Federal, State, and local fire protection agencies in southern California. MACS specifies the procedures, hardware, and personnel required to integrate the command-dispatch functions of the individual organizations to increase significantly both opportunities and capabilities for coordination of emergency operations, with emphasis on multiple-incident situations.[5]

MACS does not have independent operational authority. Rather, it is a formally defined extension of the command, dispatch, and support functions of the individual user agencies. MACS is a user-managed, service-oriented system designed to enhance agency operations. Individual agency authority and responsibility is not compromised or usurped.

Specifically, the Multiagency Coordination System provides

- Comprehensive and current geographic data base which includes site-specific information on cultural features, fuels, topography, risk, and values in a uniform format for all jurisdictions.
- Centralized collection, processing, and display of current information on local weather, status of agency resources, and fire activity (including perimeter, control status, and labor and equipment assigned, for major fires) for the FIRESCOPE area.
- Improved support of individual incidents through capability to predict, and assess probable consequences of, local weather, fire behavior and spread potential, and resource effectiveness.
- Dynamic centralized evaluation of major and multiple-incident situations, with the capability to coordinate agency requests for assistance and to determine the best allocation and assignment of resources to meet individual incident needs.
- Administration of ICS and MACS programs, including document control; training coordination; and data base, software and equipment maintenance.

Operations Coordination Center

The MACS functions are funneled principally through the central Operations Coordination Center (OCC), providing an improved, integrated communication system with existing agency dispatch centers and individual Incident Command Posts. The OCC is the central information and resource coordination point for MACS, maintaining applicable geographic and environmental data bases and resource activity information for the FIRESCOPE region. All agency requests for assistance (except those for local aid under established automatic or mutual aid agreements) are coordinated through the OCC (*fig. 3*). As this focal point for current regional information from all agencies, the Center can provide situation summaries to cooperating agencies, news media and other information users. But most importantly, the OCC pr[ovides] the logical site from which top command personn[el] from involved agencies can coordinate and dir[ect] integrated operations in a major emergency. The Op[er]ations Coordination Center is intended to operate fu[ll] time, with a permanent support staff, including daily a[nd] seasonal staffing and readiness levels appropriate f[or] expected system workload and related response-ti[me] requirements.

MACS is designed to provide a capability to anticipa[te] fire suppression requirements for an incident. Informati[on] collection and analysis by MACS, coupled with assessme[nt] and forecasting capabilities, will enable improved agen[cy] assessment of critical needs and evaluation of probable a[l]ternative responses, particularly during multiple-incide[nt] situations. Such advance information will permit more e[f]fective planning, and decrease the chances that unexpect[ed] events will disrupt operations.

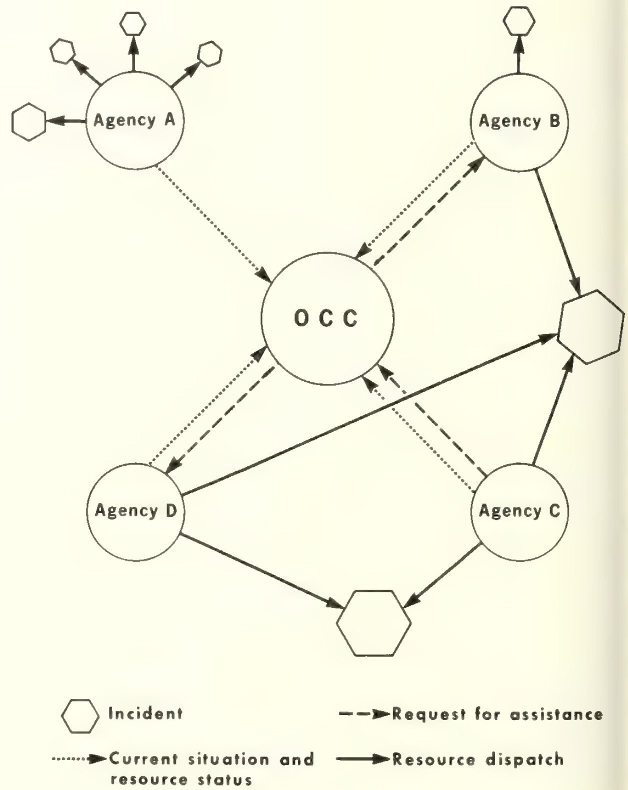


Figure 3— Multiagency Coordination System (MACS) operatio[n]. MACS activity is centralized at the Operation Coordinati[on] Center, designed to maintain current information from a[ll] jurisdictions and to assist in coordinating requests for inform[a]tion.

AJOR FUNCTIONS OF FIRESCOPE

IRESCOPE functions may be grouped into four general egories, based on system performance requirements and rational characteristics:

- ncident Command
- General Intelligence
- Planning and Support
- Communications

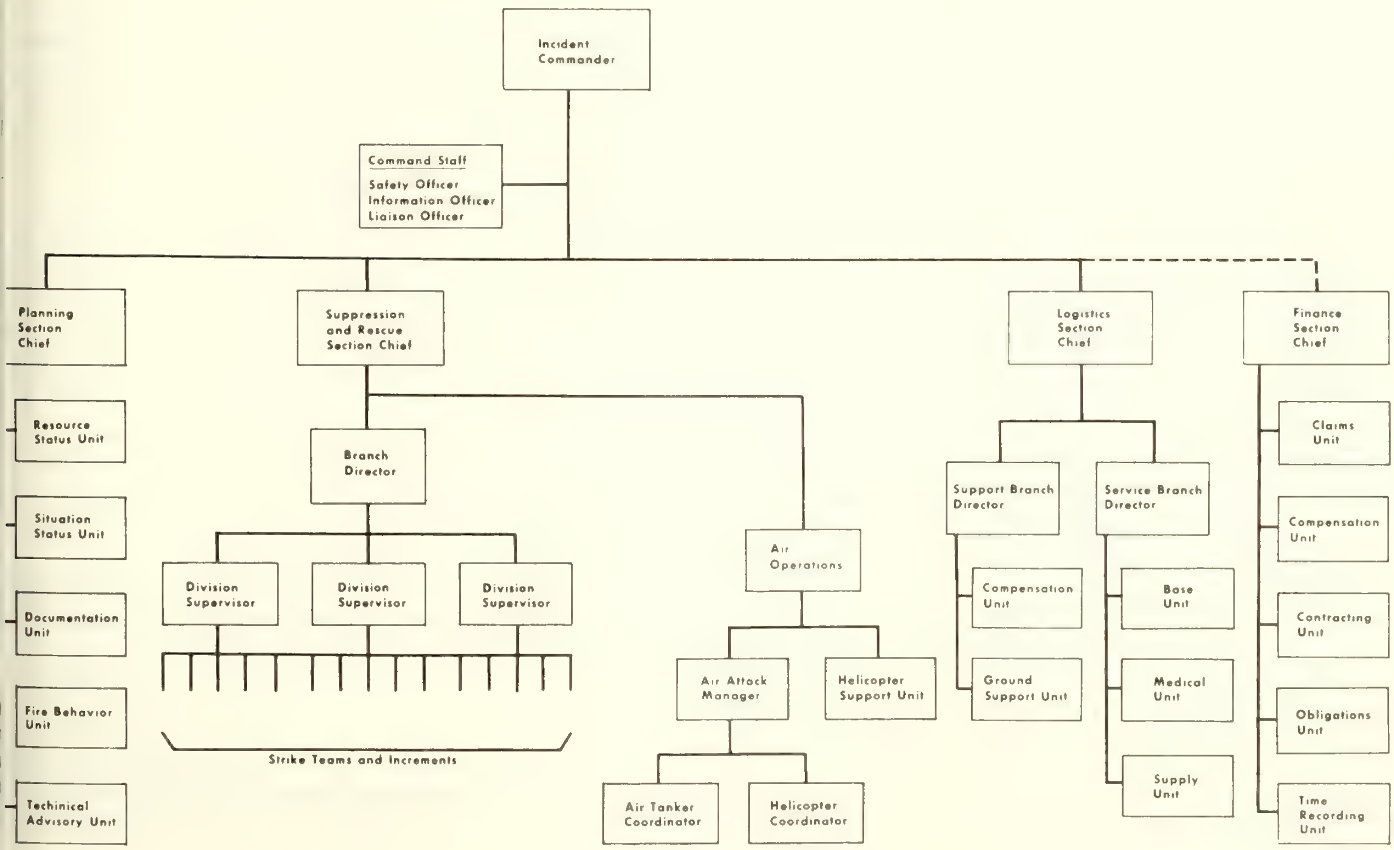
he Incident Command function addresses the manage-nt of onsite operations reponding to a specific emergency incident. The purpose is to facilitate effective and cient use of resources assigned to that incident within the pe of suppression and rescue responsibilities of the fire vices.

General Intelligence, Planning and Support, and Com-nications directly support the Incident Command Sys-. At the regional level, they also provide the capability MACS to carry out both dynamic preemergency planning and coordination of emergency responses between agencies and incidents.

Incident Command

The Incident Command provides the common organizational procedures and terminology required for agency personnel to efficiently plan and coordinate activities at a major fire or other incident involving two or more fire protection agencies. The Incident Command defines information collection, processing, and transfer requirements for system operation and identifies related hardware needs.

Incident Command System effectiveness hinges on the integration of system terminology and concepts, to the fullest extent possible, into the daily operations of each agency, including use on small, single-agency incidents. Agencywide adoption of the system is therefore central to program success. Lacking such system integration, personnel would be required to learn two emergency operating systems—one for the agency, another for ICS. These dual operating procedures would pose a high poten-



ure 4—FIRESCOPE Incident Command System (ICS) organization structure.

tial for confusion as an incident progressed from single- to multiple-agency status.[6]

The Incident Command System is an organizational and operational concept differing from that presently existing in any participating organization. Principal differences tend to be in the method of organization, the planning procedures, and the management information systems that support these procedures.

Organizational Structure

The Incident Command System typically consists of five system functions (*fig. 4*):

- Incident Command—overall system management and command
- Planning Section—operational planning
- Suppression and Rescue Section—management and supervision of tactical field operations
- Logistics Section—logistical support of incident operations
- Financial Section—fiscal accounting support for operations

The ICS organization is activated at the moment of incident response, with system positions and associated functions activated and deactivated based upon the needs of the incident command in relation to incident progress. Several functions may be performed by one individual in less complex situations. On a small fire, for example, the Incident Commander might perform all the responsibilities of the Suppression and Rescue Section, including Division Supervisor, and perhaps extend Incident Commander authority to the Planning Section, as well. Conversely, under heavy or complex jobs, responsibilities for a single position or function may be divided between two or more individuals.

The key element of the system is that only one ICS organization exists per incident, regardless of the number of agencies or jurisdictions involved. In multijurisdiction incidents, jurisdictional integrity may be ensured by jointly filling positions, where appropriate, with personnel from each participating agency, and carrying out the particular function on a coordinated basis.

System Responsibilities

Incident Command is headed by the Incident Commander who is responsible for overall operations management, including activation of the ICS organization in accordance with specific incident needs. The Incident Commander is supported by a Command Staff and assisted in the preparation of strategic plans by the General Staff, which is comprised of the Section Chiefs.

The Planning Section is responsible for collecting, analyzing, and reporting information relating to resources assigned to the incident. Such information includes incident history, current situation, prediction of probable course of incident events, and the preparation of alternative plans for future operations.

The Suppression and Rescue Section is responsible for management, direction, and execution of all field operations related to the incident. The basic tactical unit is the Strike Team, a formally defined aggregation of field resources, for example, five engines managed as a unit, although each resource element may be assigned to a special task. Strike Teams are organized by geographical or functional assignment into divisions, and, as the magnitude of the incident increases, into branches under the Section Chief.

The Logistics Section provides those facilities, services, and materials necessary to support suppression and rescue operations. Support functions include planning and staffing incident personnel requirements, communications, fueling, maintenance and repair of ground equipment, and managing the unassigned labor and equipment pool. Service responsibilities include required meals, sleeping accommodations, and medical services; and ordering and distributing supplies and equipment.

The Finance Section is maintained by those agencies requiring onsite fiscal services to support incident operations.

Procedures and Terminology

Detailed descriptions of responsibilities and procedures for each ICS organizational element are documented in the FIRESCOPE ICS manuals. A glossary of standard terms and resource definitions adopted for common usage by participating agencies is also provided in those manuals.

Supporting System Requirements

Effective operation of the Incident Command System is dependent upon the availability of a number of support systems and related equipment. These systems include the general intelligence functions of resource and situation status, the planning support capability provided by programs to predict fire spread and behavior, and effectiveness assessment of alternative strategies and tactics. In addition, positive communications are required not only between elements of the ICS organization at the incident, but between the Incident Command Post, the OCC, and the participating agencies (*fig. 5*).

Detailed performance requirements and characteristics for the support systems are presented below. Basic equipment for their application at the incident level includes:

- Mobile communications unit equipped with ICP radio communications on both FIRESCOPE-dedicated and participating agency frequencies; cached portable radios on FIRESCOPE frequencies for incident-wide

[6] Mission Research Corporation. 1974. FIRESCOPE field command operations system: conceptual design description. (Unpublished report on file at Forest Fire Laboratory, Pacific Southwest Forest and Range Experiment Station, Riverside, Calif.)

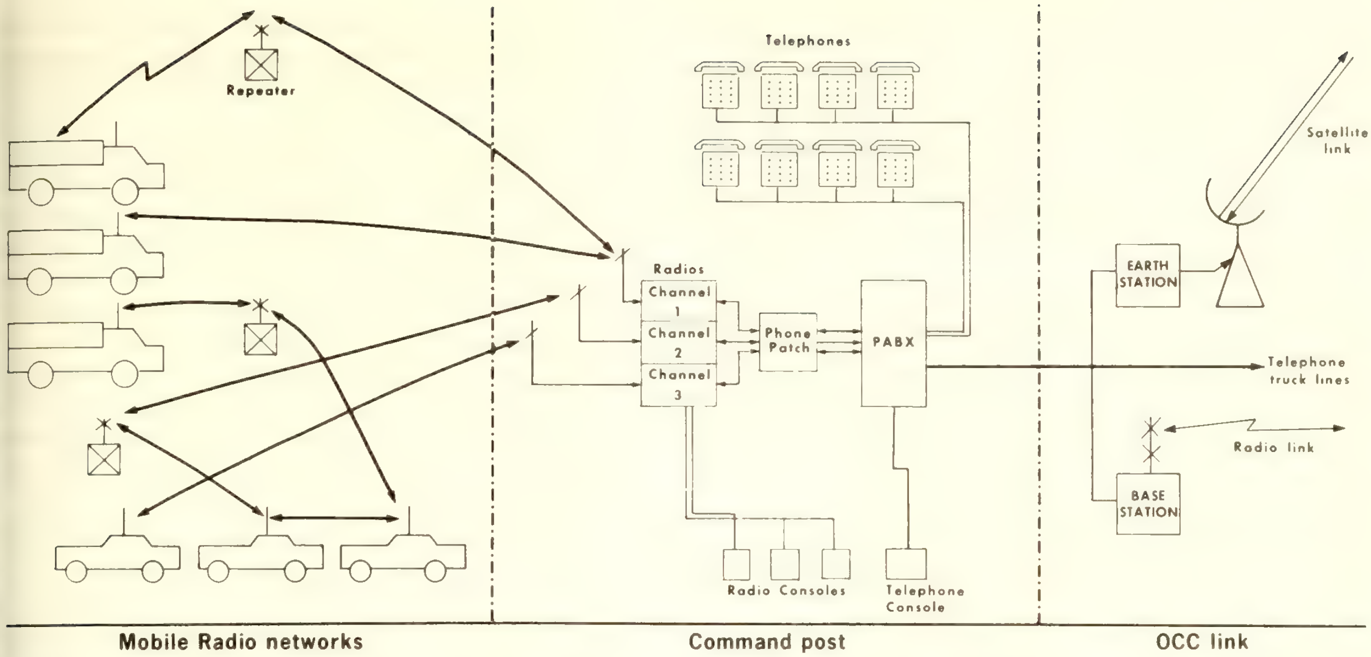


Figure 5 — Effectiveness of the Incident Command System is based on a positive communication system linking all elements.

command, logistics, status, and coordination communications; and ICP telephone system.
Mobile base unit and related equipment to establish a microwave, satellite, or other positive communications link between the ICP, the OCC, and agency headquarters.
Mobile ground station for receiving IR imagery telemetered from aircraft.
Mobile unit facilities to house command, logistics, and planning, including situation status and resource status functions.

›eneral Intelligence

FIRESCOPE system general intelligence processes ırrent information related to three specific areas:

- Suppression resource status
- Situation assessment
- Geographic data bases

his information supports not only daily operational ecisions at the incident and OCC-agency command levels, ut also agency needs related to short-range and longınge planning and training. General intelligence ranges in meliness from static topographic data stored at the OCC ɔr the entire area to dynamic status maintained at the ICP f specific resources assigned to an incident.

uppression Resource Status

The suppression resource status (RESTAT) maintains ırrent information on the location, availability, and general capabilities of fire suppression or other emergency forces. The detail and timeliness of status information maintained at the incident, the OCC, and agency dispatch offices will differ, depending on differing information requirements.

At the individual incident, status-keeping is carried out by the Resources Status Unit, a part of the Planning Section. The unit maintains information on all resources allocated to the incident, both by resource item and by incident summary. The information for individual resource elements includes

- Identifier (agency and unit number)
- Type
- Current status (active, available, or out-of-service)
- Current location (division or unit assignment, name of camp staging area, or if en route, the estimated time of arrival)
- Pertinent performance factors

Both a manual and an automated system have been proposed for maintaining status information. The manual system consists of compact racks clearly displaying cards which are color-keyed by resource type, status, location, or assignment for each element, and upon which identifier and other data are entered (Chase 1977b). The automated system requires the availability of a mini- or microprocessor and related peripheral equipment. Such a system could be transported to the ICP in a mobile unit, or—if a suitable positive data communication link can be assured—located at the OCC and accessed via terminals at the incident.

The manual system is technically less complex than the automated system and therefore involves less cost and risk

to establish; however, physical constraints on data entry and retrieval (relating to speed and location) limit the utility of the manual system under heavy-load conditions when efficient performance is most important. The manual system should therefore not substitute for the automated system, but realize its potential on small- to medium-sized incidents and as backup to the computerized system.

RESTAT at the regional level relies on the agencies to maintain status of their respective resources, at least during routine activities. In general, the OCC is concerned with remaining apprised of *levels* of activity within each agency and thus being aware of resource availability should a major incident occur. Exceptions are scarce specialized resources, such as fire retardant air tankers, helicopters, and key crews, which are available to other agencies for emergency aid use. Status of these individual units is routinely maintained at the OCC. During major emergencies, the OCC will maintain closer track of uncommitted resources of all types, as appropriate, as resource commitment by agencies becomes heavy. For this purpose, the OCC maintains a current record of all resources assigned by individual agencies to each major incident.

Information collection, transfer, processing, storage, and display for RESTAT within MACS can be manual, automated, or a combination thereof.

A fully automated system involves the integration of individual agency-dedicated miniprocessor resource status systems. Summary or specific status information required for centralized coordination can be transferred automatically to the OCC system for processing and display. The status information is then available for further summary and transfer to other interagency coordination centers within the State or Nation.

In a less sophisticated automated system, data would be entered into the OCC system through terminals at agency dispatch offices, or at the OCC from agency dispatch office telephone reports. Both options impose a reporting workload on agency dispatch personnel above that required for the fully automated system.

The OCC manual system implies an essentially larger version of the card and rack system proposed for the ICP. Both the card and rack system and the centralized data entry terminal system would require a reliable communications link between agency dispatch offices, ICP's and the OCC.

Situation Assessment

Situation assessment consists of data storage and display required to assess the existence of, or potential for, incidents within the jurisdiction of participating fire services. Assessment data include the number, size, and locations of incidents; damages sustained and values threatened; progress of work on individual incidents; access, terrain, and vegetation; and current and expected weather. Efficient transfer of situation assessme information between the incident, agency headquarter and regional coordination (OCC) levels is essential f system operation.

At the incident, the Situation Status Unit provides t data specifically required for strategic and tactical pla ning, including a chronological record of events. addition, the Situation Status Unit provides general in dent information to the OCC as a basis for interagen regional resource allocation and coordination decisio and for public information purposes.

Data to support situation assessment are obtained fro a variety of sources. Basic geographic data are available map or digital form from the geographical data base mai tained at the OCC. Up-to-date regional fire activity info mation, including specific locations of problem fires, w be provided to the OCC by individual agency dispat offices via a dedicated communications system.

Fire perimeter and related intelligence on large fires a obtained at the incident by a combination of visual grou and aerial scouting, and aerial infrared remote sensin with telemetry of the latter data in near real-time to t ICP and OCC (Warren 1975). Forward-looking infrar (FLIR) and similar heat-sensitive, camera-TV type displ systems may be employed to acquire tactical intelligence portions of a fire (or other incident) obscured by smoke darkness; but the principal FIRESCOPE system is an line-scan operating at an altitude of 5,000 to 20,000 feet produce the mapping imagery required for system op ations. Telemetry of this thermal map to portable grou stations at the ICP and a fixed receiver at the OCC w provide both stations with a printout of the current fi perimeter, burning intensity, and related data required f tactical and strategic planning. Information from th source is also essential for updating previous computer fi model perimeter predictions, as well as improving curre accuracy. If a portable ground station is not available the incident, imagery or a map representation can be tra mitted from the OCC via telecopier.

Regional meteorological data is required for centraliz assessment of current and expected burning conditio flooding potential, and other weather-related emergenci Such data is also necessary input to the computerized fi perimeter and intensity prediction models. Data collecti for the variety of operational and planning purposes i volved is through an extensive fixed regional network a portable networks displayed at individual incidents.

The recommended regional network consists of appro imately 30 unattended stations measuring average win speed and direction, current temperature and humidit and precipitation. Ten of these key locations would rep data on an as-needed basis. The remaining stations wou be self-timed and transmit data at 3-hour intervals. Bo types of stations would utilize the National Environmen Satellite Service (NESS) and Geostationary Operatio Environmental Satellite (GOES) to relay data to t

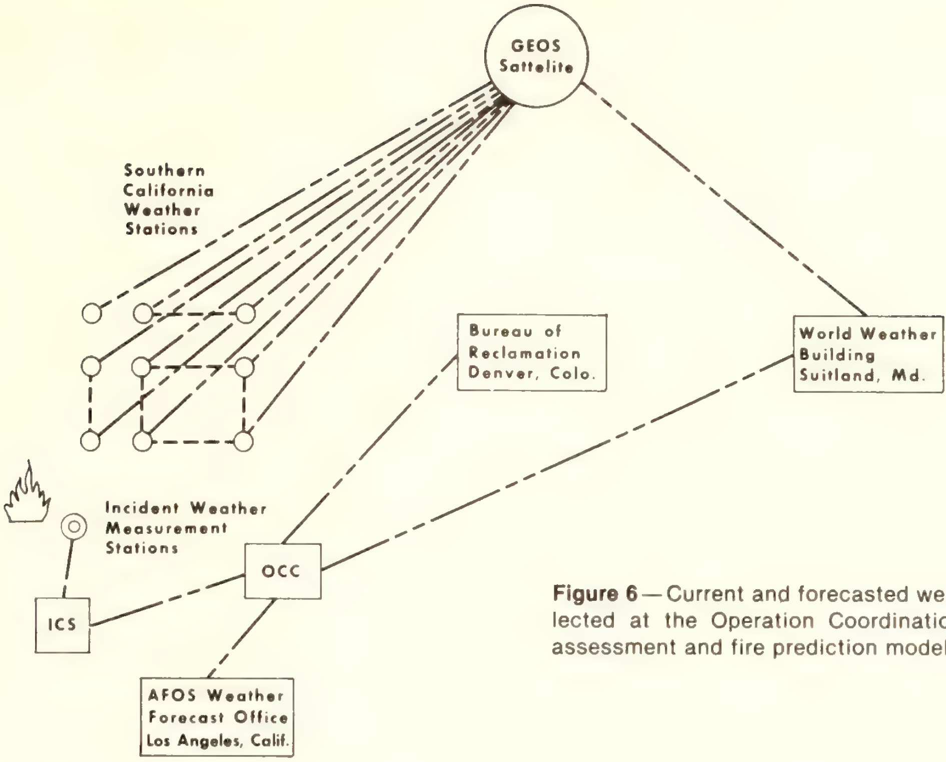


Figure 6—Current and forecasted weather information is collected at the Operation Coordination Center for situation assessment and fire prediction modeling.

ational Weather Service computer in Suitland, Mary-nd. The data would then be automatically transmitted by hone line to an OCC minicomputer for processing, stor-ge, and display. Additional observations and forecast ıformation will be obtained from the National Weather ervice AFOS (Automation of Field Operations and Serv-e) network and from computerized forecast data pro-ided by the Bureau of Reclamation in Denver, Color (*fig*).

To supplement the fixed network, portable systems con-sting of up to six remote stations can be deployed in the icinity of major incidents. These stations are designed to adio transmit data upon command from a base station ocated at the ICP, where the data would be recorded for ocal use and relay to the OCC.

eographic Data Base

Geographic data are provided in map or digital form. Map-type data are presented uniformly for all agencies on JSGS quadrangle orthophotos and overlays at scales of :24000 for the entire FIRESCOPE area and 1:6000 for he higher value front country, wildland-urban interface reas. Information displayed includes topography (con-ours and drainages enhanced), vegetative cover with fuel lassification (type and age), political boundaries, geo-raphic names, and cultural features such as roads, struc-ures, powerlines, fuel and firebreaks. These orthophotos nd overlays would be used at incidents, agency head-uarters, and the OCC.

Digital representation of the above data is stored at the OCC and accessed through the Center's ADP system. Data stored in digital form, and principally required by the various programs within the FIRESCOPE information management model, include elevations at approximately 1-acre (205-foot) resolution, transportation network, resource, fuel type and age to a 4-acre resolution, and location of appropriate fire control facilities.

Planning and Support

MACS planning and support functions are principally located at the OCC because of MACS dependence on the Center's information collection, processing, storage, and display capabilities. MACS planning and support functions are designed to provide assistance to individual agencies in the following areas:

- Wildland fire initial attack effectiveness assessment
- Coordination of agency requests for assistance and allocation of resources in multiple-incident situations
- Pre-incident planning
- Communications coordination
- System training and documentation coordination
- Centralized cost accounting of interagency resource use under mutual aid agreements
- Regional, State, and National situation assessment.

MACS also provides direct incident support through local weather forecasts, fire behavior and spread predictions, evaluation of strategic and tactical alternatives, and coor-

dination and deployment of communications and intelligence systems, such as IR mapping.[7]

The capability for most of these functions is provided by the FIRESCOPE Information Management System (FIMS). This system organizes several data collection and computer model functions to perform a variety of analytical and predictive tasks (*fig. 7*) (Van Gelder 1978).[8,9]

Operational Considerations

The planning and support function is designed to respond to specific requests to the OCC from agencies or individual incidents. Though principally oriented toward wildland fire emergencies, the system has the capability to provide assistance in urban fire and major nonfire disasters.

To provide the maximum efficiency, the system design integrates regional coordinating dispatch functions of the major wildland agencies (that is, the Forest Service and California Department of Forestry) with MACS planning and support at the OCC. In addition, the system design calls for the California Office of Emergency Services, and other agencies when needed, to place coordinator personnel at the OCC specifically to carry out the MACS planning and support functions during major incidents. In this manner, system activities which involve operational knowledge and decisions are performed by qualified agency operational personnel.

In recognition of its emergency capabilities and responsibilities, MACS should be maintained at full-time operational preparedness at a level appropriate to expected workload and response time required for any emergency situation.

Initial Attack Assessment

The FIMS Initial Attack Assessment module provides rapid assessment of early wildland fire behavior and the degree to which dispatched attack forces will be able to contain and control that fire.[10] The computer program will be stored on OCC data processing hardware and may be

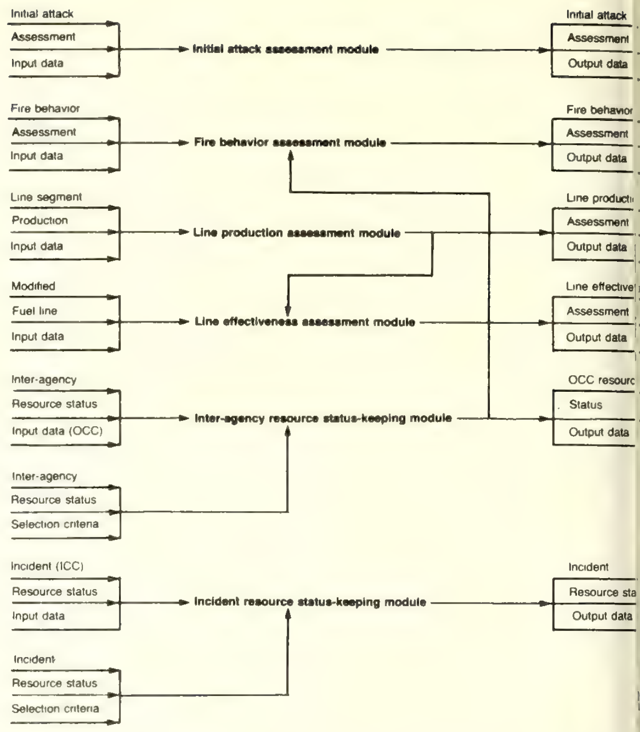


Figure 7—FIRESCOPE Information Management System (FIMS) organizes data processing and modeling functions to provide information required for system operation.

accessed by individual major agencies via their dispat office. Estimated turnaround from data entry to progra output is less than 5 minutes. Within that time, dispat and command personnel will be provided with an estima of the fire's potential and a probability-over-time fact within which dispatched attack forces will be able achieve containment and control. Unacceptably lo estimates of success probability can be countered by di patching reinforcements even before the initial forc arrive at the incident (*fig. 8*).

Interagency Resource Use Coordination

MACS interagency resource coordination at the OC provides the means for expedient and efficient assistan on a regional basis. The OCC provides a single sourc through which all needed resources and services (exclusiv of those secured through mutual or automatic aid agre ments) can be requested. This centralized coordination made possible because the OCC remains apprised of cu rent and anticipated activity throughout the FIRESCOP region, including existing and potential levels of resourc commitment by each agency. With such information, th OCC can quickly determine the closest available resource requested and thereby coordinate the necessary alloca tions, as appropriate, according to established authorizin local, State, or Federal procedures and legal agreements.

In multiple-incident situations when resource demand begin to exceed availability, at least in the short run, th

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[7] System Development Corporation. 1977. FIRESCOPE Operations Coordination Center detailed design requirements. (Unpublished contractor report on file at Forest Fire Laboratory, Pacific Southwest Forest and Range Experiment Station, Riverside, Calif.)

[8] Mission Research Corporation. 1975. A simulation for wildland fire management planning support. Vols. I-IV. (Unpublished report 7512-6-1075 on file at Forest Fire Laboratory, Pacific Southwest Forest and Range Experiment Station, Riverside, Calif.)

[9] Mission Research Corporation. 1976. Wildland fire modeling for planning support. Vols. I-IV. (Unpublished report 7611-3-876 on file at Forest Fire Laboratory, Pacific Southwest Forest and Range Experiment Station, Riverside, Calif.)

[10] Mission Research Corporation. 1976. Users guide: experimental initial attack evaluation model. (Unpublished contractor report 7611-1-376 on file at Forest Fire Laboratory, Pacific Southwest Forest and Range Experiment Station, Riverside, Calif.)

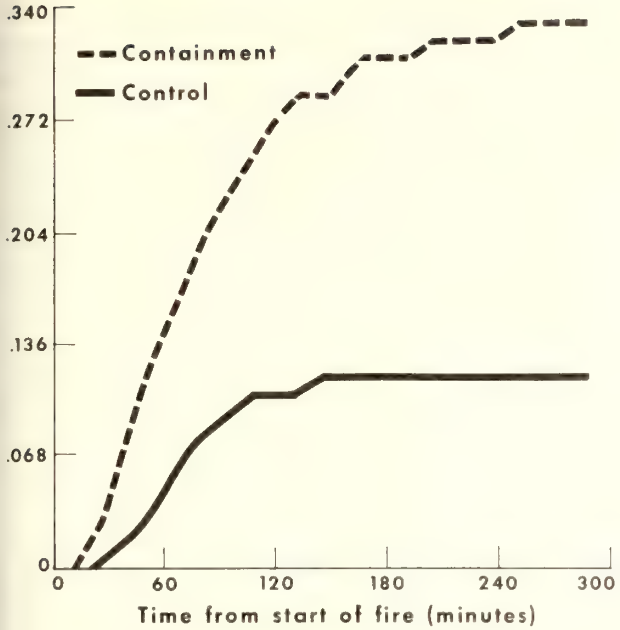

Figure 8—Sample computer output of the Initial Attack Assessment Model. Both predicted fire growth and probable success of the dispatched forces are shown.

OCC can assist agency decisionmakers in setting resource allocation priorities. In fact, in any major multiple-incident emergency, it is assumed that top command personnel from the major agencies involved will assemble at the OCC facility to personally coordinate resource allocation and other interagency activities. The OCC provides support for such decisions through FIRESCOPE Information Management System. FIMS furnishes current, regionwide resource status and situation assessment information for all types of incidents, including wildfire forecasting. FIMS forecasting modules permit assessment of potential behavior, spread, and damage of large fires; anticipates resource needs 2 to 6 hours in advance, and evaluates probable effectiveness of resource allocation and strategy alternatives.

The OCC also provides centralized liaison with cooperating nonfire agencies during major situations. The OCC can assist these agencies in coordinating diverse service requests because the Center retains current activity status on a regionwide basis and is capable of making at least limited forecasts of probable future requirements.

Pre-incident Planning

Agencies can use the OCC fire modeling and data base capability for a variety of purposes: to develop and implement variable staffing plans (such as on a daily, weekly, risk, or hazard basis) for existing initial attack situations; to plan the most effective initial attack force locations and associated preplanned dispatch assignments, particularly where opportunities for multiagency resource involvement exist; and to prepare general contingency plans for major incidents on a multiagency basis. Contingency planning considers the most likely occurrence locations for major incidents and generates models to effectively deal with probable resource and service requirements. Contingency planning is also considerably valuable in individual and multiple-agency training.

Communications Coordination

An important OCC function is the coordination of system-furnished communication cache equipment and agency- and system-assigned frequencies on a noninterfering basis among major multiagency incidents, because radio frequencies available for interagency communication are limited. The OCC coordination staff will assist agencies in setting priorities, where appropriate, and will be responsible for assigning frequencies and equipment along interagency guidelines to provide essential services to the maximum number of simultaneous incidents.

Training and Documentation Coordination

Standardized experience, training, and course material are required of all participating agencies to ensure the success of the multiagency system.[11] The OCC training coordinator will coordinate the development of these requirements and assist agencies in preparing individual, but uniformly responsive, training programs. Integral to this program is the coordination of interagency training sessions and records of individual qualifications for position assignments on multiagency incidents.

A major responsibility of the training program is to issue and maintain all FIRESCOPE system documents, including operational procedures and position descriptions.

Cost Accounting Services

The OCC will maintain accounting records of all interagency resource assistance which it coordinates. The OCC will also provide a basis for reimbursement control under documented aid agreements between participating agencies.

Communications

The FIRESCOPE Communication System is comprised of three subsystems:[12]

- Incident Command System serving ground operations

[11] System Development Corporation. 1977. FIRESCOPE Incident Command System documentation and training support. (Unpublished final report TM-5961 on file at Forest Fire Laboratory, Pacific Southwest Forest and Range Experiment Station, Riverside, Calif.)

[12] Institute for Telecommunication Sciences and U.S. Department of Commerce Office of Telecommunications. 1977. Incident communications design for FIRESCOPE. (Unpublished report on file at Forest Fire Laboratory, Pacific Southwest Forest and Range Experiment Station, Riverside, Calif.)

- Interface linking the Incident Command System with the OCC and agency headquarters
- Interface linking the OCC with agency headquarters and other data sources.

The system design provides a positive information-data transfer link (in proportion to volume and urgency of expected traffic) between appropriate system-subsystem components. Several criteria were established as design goals:

- The system would complement agencies' existing systems and operating processes.
- Existing agency communications equipment would be utilized, except where available advanced technology made addition or replacement a clearly desirable alternative for operational purposes.
- System technology would be proven and commercially available at competitive costs for 1981 implementation.
- Telephone communications would be preferred whenever practical; radio would be used primarily for local communications where telephone is not feasible, such as for portable-mobile communication applications.

Incident Communications

The principal ICS communication subsystem compo- nents, which provide all intra-incident communications are command, planning, and logistics at the Incident Com- mand Post, and air and ground units in the field opera- tions (*fig. 9*).

Incident communications will consist of a combinatio of agency-furnished equipment on agency operational fre- quencies and FIRESCOPE system equipment on system dedicated channels.

Since communications requirements vary according t incident type, size, and location, the design proposes flexible, modular approach to meet incident needs, rathe than rigidly specifying equipment and frequencies. In con- junction with incident and agency communications per- sonnel, the OCC would be responsible for planning an coordinating the assignment of FIRESCOPE system hard- ware and frequencies to each incident beyond the initia response stage. Such system coordination would preclude or minimize, interference between incidents in multiple incident situations and maximize system efficiency as th number of simultaneous incidents increased.

The incident communications center is a mobile uni which allows onsite incident radio and telephone commu

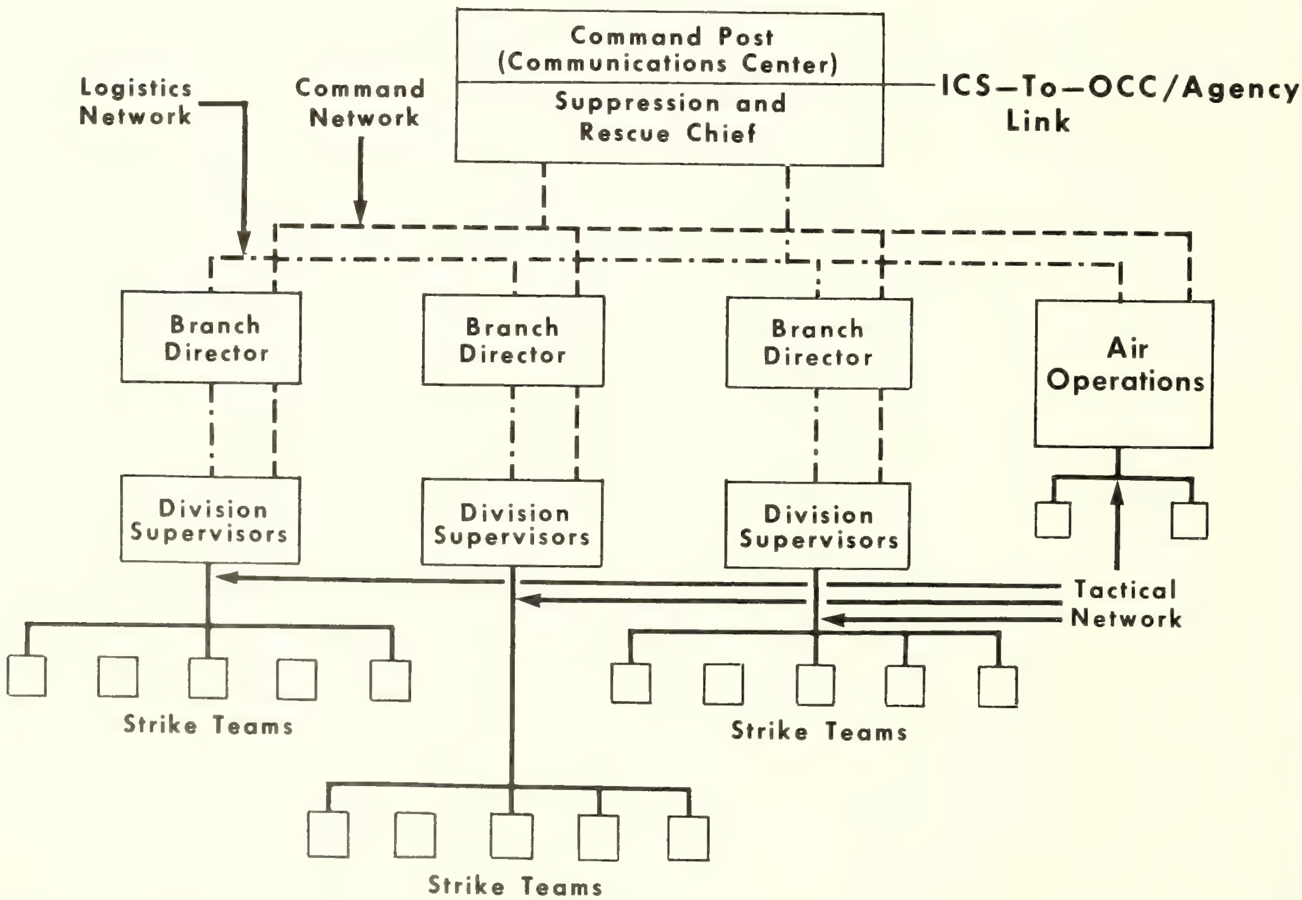

Figure 9—FIRESCOPE incident communication networks.

cations with all assigned units, the OCC, or agency headquarters.[13] The equipment modules which would be transported to the incident unit include:

- Base station radio equipment covering all participating agency- and FIRESCOPE-assigned frequencies
- Telephone equipment to establish an ICP telephone system, including links with the base radio system and external telephone company (or satellite-earth terminal) lines
- Cached portable multichannel radios and portable repeaters on FIRESCOPE system frequencies
- Portable remote weather telemetry system
- Data terminals and ADP hardware
- Remotable console positions for message center and message switching functions.

Planned FIRESCOPE ICS radio communications with and between field units utilize existing agency radios and frequencies for tactical communications within and between an agency's Strike Teams, between the Strike Team and its Division Supervisor, and between air and air-and-ground units. These existing tactical ground and air networks satisfactorily provide the intra-agency communications typically required for all suppression and rescue operations. The standard agency communication procedures will thus continue in the FIRESCOPE system operation with little or no effect.

Command, logistics, and interagency coordination communications at the division level and above (between field positions, including base camps and staging areas, as well as supervisory personnel, and field positions and the OCC) will be on two FIRESCOPE-frequency networks assigned to the incident by the OCC. Portable radios would be provided from the ICP communication unit cache. The command and logistics networks are essentially parallel. The command network coordinates situation and resource information, as well as strategic and tactical orders. The logistics network serves support and service functions. A minimum of eight dedicated channel-pairs should be available to these networks to minimize possible interference in multiple-fire situations. Twelve channel-pairs are recommended.

Incident-OCC Communications

Communications between the ICP and the OCC or agency headquarters will use commercial telephone whenever available with sufficient capacity and reliability.

Where suitable telephone service is lacking, a communication satellite link is proposed. The satellite would be accessed at the incident through a portable ground terminal at the ICP. A fixed terminal would be provided at the OCC and communications with agency headquarters (or other points) would be via OCC commercial telephone link (Warren 1977).

OCC-Agency Communications

Communications between agency headquarters and the OCC will be via a combination of leased and commercial telephone line service and a State microwave intercommunication network. A minimum of one dedicated line between each major agency and the OCC will be required for data transmission; additional incidental voice communication requirements can be satisfied by phone and State microwave intercommunications.

An emergency backup will be maintained at the OCC to ensure radio communication with each agency headquarters, as well as monitoring of agency dispatch and tactical operations channels when necessary.

MAJOR HARDWARE, FACILITIES, AND STAFFING REQUIREMENTS

FIRESCOPE is an integration of participating agency personnel and equipment; collectively managed hardware, software, facilities, procedures; and system personnel required to perform specialized system tasks. The capacity of the system to respond to coordination and support demands by individual agencies is proportional to the extent of these collectively managed resources. System integrity must therefore consider not only the probable number, type, size, and timing of demands, but also the performance requirements and associated limits of acceptable response degradation as design capacity is exceeded by simultaneous job requests.

The design recommendations for system-provided equipment, facilities, and staffing are predicated on a system capacity that meets the requirements of a situation characterized by five simultaneous and similar, major, multiagency fires or incidents. Consideration must, however, account for variations in individual incident size, scope, and complexity, and the resulting demands on system support. Thus, the system design capacity could in reality be overwhelmed by two or three simultaneous catastrophic incidents, or it could adequately meet the needs of 12 large incidents in a relatively uncomplex situation. In actuality, the amount of system-provided hardware and support staff is ultimately a funding decision, based on expected workload and some rational standard for minimum acceptable system performance. As system capacity is reached, an operational decision will be required to choose between servicing additional support

[13] Forest Service, U.S. Department of Agriculture. 1978. FIRESCOPE Incident Command Post communication system design. (Unpublished report, Research Work Unit 2110, on file at Forest Fire Laboratory, Pacific Southwest Forest and Range Experiment Station, Riverside, Calif.)

requests at the expense of downgrading service to ongoing incidents, or cuing in new requests and responding to them only as the needed system function again becomes fully available.

Incident Command System

Facilities and Equipment

The centralized Incident Command functions are carried out at the Incident Command Post (ICP), normally located at the incident base. Standard facilities and support equipment are provided by communications trailers and support trailers available for assignment to major incidents, since base locations are largely unpredictable and available facilities at any given site are subject to considerable variation. The communications trailers provide ICS base personnel with appropriate work space and transport appropriate specialized equipment to the incident. These units could be maintained and operated by individual agencies or be designated FIRESCOPE units and held for assignment to multiagency incidents. In either case, a 40- by 8-foot semitrailer is recommended. Oncall contract tractors would be used to move the units if agency equipment were unavailable.

The support trailer would provide suitable work space, equipment, and supplies for the principal command and planning staff. The support trailer would house RESTAT, SITSTAT, as well as the incident minicomputer and related peripheral equipment.

The communications trailer will provide console positions for four radio operators and a telephone operator and would be equipped to carry out the RESTAT function in the manual mode in the absence of other facilities.[13]

The installed communications equipment will include:

- Five base station synthesizing transceivers (three to cover FIRESCOPE-assigned channels, and two to cover agency-operated frequencies)
- One base station for the portable remote weather telemetry network[14]
- One telephone PABX (30 internal, 8 external line capacity), with radio-phone patch capability, for base internal communications and as a base link with the outside
- Appropriate support generating and air conditioning. The unit will also carry for distribution:
- A cache of 40 portable, 6-channel transceivers on FIRESCOPE frequencies
- Thirty telephones for base communications
- Two remote consoles to provide direct radio communication at the support trailer or other ICP facility

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[14] Forest Service, U.S. Department of Agriculture. 1977. FIRESCOPE portable remote meteorological system design. (Unpublished report, Research Work Unit 2110, on file at Forest Fire Laboratory, Pacific Southwest Forest and Range Experiment Station, Riverside, Calif.)

- A portable 6-station remote weather telemetry syste
- Two programmable transportable radio repea s covering FIRESCOPE channels.

The communication link between an individual incid t and the OCC or individual agency headquarters will direct commercial telephone service, whenever possib. For situations where this service is unreliable or unava- able, the FIRESCOPE system design recommends th portable satellite communication ground stations f assignment to incidents by the OCC (Warren 1977).

The FIRESCOPE system will have five mobile grou receiving units available for OCC assignment to prov direct reception of IR line-scan mapping imagery at t incident.[15]

Personnel

All ICS positions will be filled by qualified regular p sonnel from the fire protection agencies. Assignm t will be made by the agencies involved in the particu incident, or through the OCC upon agency request.

Multiagency Coordination System

Facilities and Equipment

The Muiltiagency Coordination System operates out a 7000-square-foot facility that serves as the FIRESCO Operations Coordination Center. The California Depa ment of Forestry and the U.S. Forest Service use the same facilities for regional coordinating dispatch oper tions. Though integrally associated with these two wil land protection partners, FIRESCOPE OCC acts indepe dently under joint management of the FIRESCOPE Boa of Directors. Comprised of representatives of the active participating and financially supporting agencies, t Board of Directors sets general policy guidance for t OCC.

The Operations Coordination Center consists of the f lowing principal hardware components:

- Data processing system consisting of three integrat miniprocessors and related data entry, storage, a display devices. Three central processing units (CPU' perform three simultaneous functions, including redundancy feature that lets the system remain operab in a hardware failure[16]

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[15] Forest Service, U.S. Department of Agriculture. 1977. FIRESCOP infrared telemetry system design. (Unpublished report, Research Wo Unit 2110, on file at Forest Fire Laboratory, Pacific Southwest Forest a Range Experiment Station, Riverside, Calif.)

[16] Mission Research Corporation. 1977. FIRESCOPE informati management system performance specification and implementation pla (Unpublished report on file at Forest Fire Laboratory, Pacific Southwe Forest and Range Experiment Station, Riverside, Calif.)

- Weather information processing terminal connected to the NWS AFOS network
- Internal PABX system to provide, preferably, 30 internal and 8 external communication links
- Drop connection with the State microwave intercom network
- Ground unit for receiving telemetered IR line-scan imagery
- Satellite communication ground station.

miniprocessor and data communication link with the CC will be installed at the dispatch offices of participang agencies to perform information storage and transfer inctions of RESTAT and SITSTAT.

An automatic weather data collection and telemetry netork consisting of approximately 30 remote stations will installed to cover the FIRESCOPE area.[17]

oftware

The following FIRESCOPE Information Management ystem (FIMS) modules are recommended for implemenition on OCC data processing equipment:[16]

- Initial Attack Assessment module to estimate small fire behavior and initial attack force effectiveness from generalized location, fuel, weather and slope information, and specific initial force units dispatched.
- Fire Behavior Assessment module to calculate expected fire perimeter locations for specified times based on point of origin and site-specific fuel, weather, and topography data
- Line Production Assessment module to estimate control line production for specified line segments by typical fire suppression resources used in southern California, including the effects of local fuel on construction difficulty and line width parameters, topography and weather, as well as personnel fatigue factors
- Line Effectiveness Assessment module to estimate probable effectiveness of specified proposed control line segments, considering fire behavior, line production, completion time, and stability
- Resource Status Keeping module to maintain files of interagency resources and the status of all resources assigned to major incidents
- Meteorological Computation and Forecast module to process local weather observations from the regional network or other sources, and numerical and forecast information, thereby enabling local interpolation of current conditions and forecasting of expected meteorological values for the Fire Behavior module.

The following data bases will be maintained:

- Vegetation, to include fuel type and age[18]
- Topography
- Transportation network
- Meteorology
- Fire and other emergency resources and facilities

Personnel

The administration and performance of FIRESCOPE OCC service and support functions will require approximately a 14-member staff (*table 1*). Approximately half of these positions should be filled by FIRESCOPE system employees; the remaining positions should be filled by agency personnel assigned to the OCC for a tour of duty, with assignments rotated periodically among the agencies.[7]

System employees (versus agency employees) could be hired through a single agency, such as State Office of Emergency Services. The positions relate specifically to MACS management.

Field maintenance of communication and weather station equipment will require additional technical support that could be shared by agency personnel.

As OCC workload increases during emergency situations, operational personnel from individual agencies involved in incidents would be temporarily assigned to the OCC to assist resource coordination and incident support functions.

Locating local NWS personnel at the OCC is strongly recommended because of the meteorological interpretation necessary for modeling and situation assessment. Alternatively, a FIRESCOPE system staff meteorologist will be required in addition to the other proposed positions.

NATIONAL APPLICATION OPPORTUNITIES

FIRESCOPE is a system oriented toward specific southern California problems and capabilities. With few exceptions, the conditions addressed by the system are not paralleled elsewhere in the United States. It follows, therefore, that implementation of the total system would not be operationally or economically justified outside of the seven-county FIRESCOPE region.

Considerable technology has been developed which does, however, have national implications and which can

[17] Forest Service, U.S. Department of Agriculture. 1977. FIRESCOPE ieteorological station network design. (Unpublished report, Research /ork Unit 2110, on file at Forest Fire Laboratory, Pacific Southwest orest and Range Experiment Station, Riverside, Calif.)

[18] Forest Service, U.S. Department of Agriculture. 1977. FIRESCOPE fuels data base report. (Unpublished report, Research Work Unit 1652, on file at Forest Fire Laboratory, Pacific Southwest Forest and Range Experiment Station, Riverside, Calif.)

Table 1—*Operation Coordination Center positions. Support personnel perform system administrative functions. Service personnel provide operational interface with individual agencies.*

Position	Function	Personnel required	Salary range (1977 dollars)	How staffed	When staffed
		Support area			
Supervisor	Administration	1	28-31K	Hire	Full time
Supervisor	Data processing	1	23-26K	Hire	Full time
Technician	Data processing	1	15-16K	Hire	Full time
Technician	Maintenance	2	16-18K	Hire	Full time
Supervisor	Document control	1	19-22K	Hire	Full time
Supervisor	Cost accounting	½	11-13K	Hire	As needed
Secretary	Administration	1	12-13K	Hire	Full time
		Service area			
Supervisor	Administration	1	28-31K	Agency	As needed
Coordinator	Training	1	23-26K	Agency	As needed
Coordinator	Resources	1	23-26K	Agency	As needed
Analyst	Resources	2	16-18K	Agency	As needed
Clerk-typist	Administration	2	11-12K	Agency	As needed

provide significant contributions to fire management in other areas of the country. The chief contributions of the FIRESCOPE program on a national level are:

- *Infrared Telemetry.* The prototype infrared line-scan mapping telemetry system developed for use in the FIRESCOPE region provides timeliness of delivery of the imagery. Before existing hardware can be used elsewhere, however, approval from the Interdepartment Radio Advisory Committee (IRAC) is required for additional telemetry channels, since the one presently used is limited to a specific geographical area.
- *Automatic Weather Telemetry Network.* The FIRESCOPE- recommended stations provide more versatility in quality and potential uses of collected weather data than single-purpose stations currently under consideration for National Fire Danger Rating, with only minor, if any, increase in costs.
- *Incident Command System.* The concepts of uniform terminology, emergency organization structure, and cooperating agency procedures initially were not thought to be radical innovations. Program development to date, however, indicates that this may be one of the more significant contributions of FIRESCOPE, with correspondingly minor implementation cost. The Incident Command System as well as improvements in present wildland organization and operating procedures deserves further study for expanded application.
- *Multiagency Coordination.* Development of the FIRESCOPE system involved a detailed, systematic analysis of one of the more complex coordination situations confronting any fire protection agency in the country. The experience gained should therefore be utilized to develop sound solutions to both single-and multiagency coordination problems elsewhere. Tl FIRESCOPE Operations Coordination Center, uniq in its particular role in southern California, can provi a model for other local coordination centers, f example, in the study of Boise Interagency Fire Cent operations. A systematic analysis of operation problems and requirements of candidate locatio would, of course, be required prior to any applicati of specific technology.
- *Fire Information Management Systems.* Developmen in information management perhaps offer the mo potential for extending FIRESCOPE technology other areas of the country. Unfortunately, fire manag ment functions have tended to lag behind other resour management activities in the area, yet many oppo tunities exist to increase effectiveness and efficiency data collection, processing, storage, retrieval, an display to meet a variety of fire-oriented needs.

One example of technological spinoff is FIRE CASTING, a computerized method for forecasting fi spread and behavior based on specified fuel, weather, an site parameters. Developed as an *interactive* comput program, FIRECASTING enables the field user to appl standard fuel models or create one to meet specific loc conditions. This program thus provides a major tool fc preparing fire use prescriptions and planning prescribe fire operations.[19]

Similar contributions can be expected from operation fire suppression information system improvements a

[19] Van Gelder, Randall J. 1978. FIRECASTING operator's guid Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. (Unpul lished manuscript on file at Forest Fire Laboratory, Pacific Southwe Forest and Range Experiment Station, Riverside, Calif.)

al, regional, and national levels. The benefits of uni-m data bases and integrated resource and situation tus-keeping systems have been demonstrated by the RESCOPE program and are equally applicable to other ıltijurisdictional situations.

UMMARY

The FIRESCOPE system was designed to provide an fective and efficient solution to operational coordination quirements and problems of the major fire protection encies serving the southern California urban-wildland mplex. These agencies are responsible for providing a riety of emergency services over an area of more than ,000 square miles containing 12 million people, high lue improvements, and broad expanses of some of the ost flammable vegetation found in the world.

Major wildland fires are a common annual occurrence this Mediterranean-like climate which typically gives the ea 4 to 6 months of almost total drought. In addition, e region is threatened with infrequent, but potentially sastrous, urban emergencies precipitated by flooding, rthquake, and fire. Any major incident requires and ceives fast, close cooperation from fire services in the ea. The FIRESCOPE Program is directed towards im-roving the effectiveness of this excellent cooperative orking arrangement.

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...Conducts forest and range research at more than 75 locations from Puerto Rico tc Alaska and Hawaii.

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...Represents the research branch of the Forest Service in California, Hawaii, and the western Pacific.

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FIRESCOPE is a system developed to improve the capability of firefighting agencies in southern California in allocating and managing fire suppression resources. The system provides an effective and efficient solution to operational coordination requirements and problems of the major fire protection agencies serving the southern California urban-wildland complex. Major wildland fires are a common annual occurrence in this Mediterranean-like climate which typically gives the area 4 to 6 months of almost total drought. In addition, the region is threatened with infrequent, but potentially disastrous, urban emergencies precipitated by flooding, earthquake, and fire. The FIRESCOPE program is directed towards improving the effectiveness of the close working arrangement of fire services in the area in response to any major incident.

Retrieval Terms: FIRESCOPE, fire management systems, agency coordination

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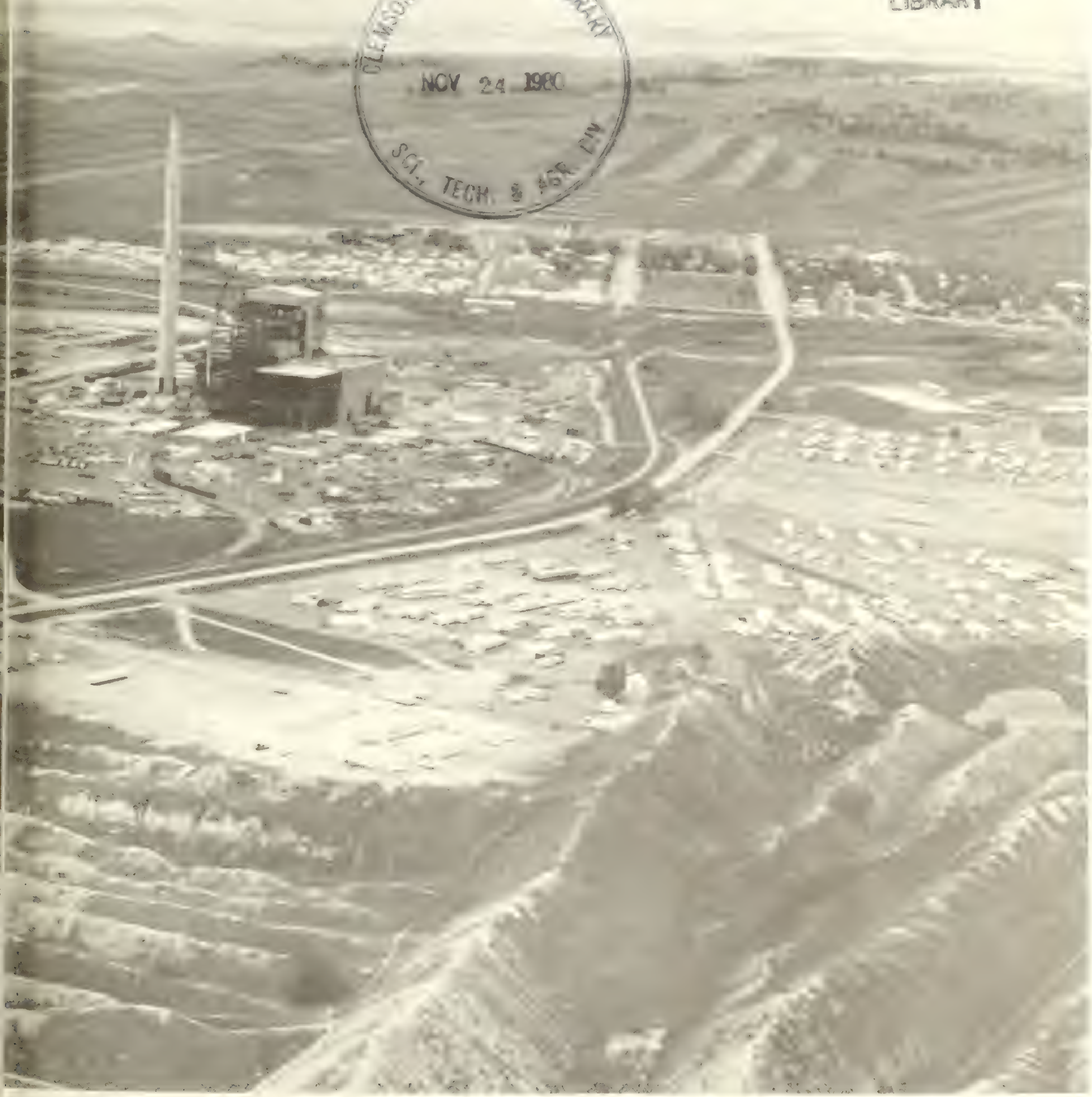
Predicting Events in the Development of a Coal Surface Mine in the West

Lynn M. Ferrante Edward C. Thor



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CONTENTS

Because large areas in Western United States are underlain with coal deposits and because coal provides a source of nergy needed in our present energy crisis, pressure to mine is coal is continually growing. Changes in the level of ining activities in rural areas can result in sudden and severe hanges in every facet of community life. The opening of a ine, or a major expansion of a mine, can promote a "boom-own" phenomenon; the closing of a mine can leave large ortions of a community unemployed. When any of these vents happen quickly, the resultant changes may catch local eople by surprise, thereby compounding the disruption.

Local officials and administrators of Federal and State gov-rnments often bear the brunt of responding to these disruptions. chool systems suddenly find their enrollment doubled, tripled, r cut to one-half or less in the course of a couple of years. Other ommunity services, such as health facilities, police and fire rotection, or power, water, and sewage districts become either eavily overloaded or overbuilt. Public leaders find that their ommunities have new interests, new concerns, and different olitical structures, some of which require changes in leader-ip. Federal land managers find themselves caught up in con-oversy and facing different administrative responsibilities: a ublic with different values makes different demands of public nds.

Federal land managers are included in the group of officials d administrators affected by changes in mining activities for vo reasons. First, much of the land in the West is Federal land, d is managed primarily by the Bureau of Land Management, .S. Department of Interior, and the Forest Service, U.S. epartment of Agriculture. Large deposits of coal underlie ese public lands and pressure to mine this coal is increasing. ven when mining occurs on private lands, often there will be ederal lands nearby that are subjected to increased demands d pressures because of the adjacent activity. Secondly, al-ough local administrators of the Bureau of Land Management d the Forest Service represent the Federal government and ontrol the surface resources of the land they manage, mining ws permit them only limited and sharply defined authorities to ontrol mining activities. As local administrators of these Fed-ral agencies, therefore, they often find themselves in situations milar to those of administrators of community and State gov-rnments.

If local officials and Federal and State administrators are able predict changes sufficiently early, the disruption resulting om changes in the level of mining activity can be minimized. Vith advance warning, programs can be adjusted, assistance an be sought, and plans can be made to deal with the disruptions. Local officials and administrators, however, must be aware that in most instances it may be directly against the mining company's interest to provide early or advance notice of its actions. These officials and administrators, as decisionmakers, therefore, must assume responsibility to predict changes in the level of mining activity on their own.

This report presents the steps in the development of a typical coal mine in the West and describes specific signs that local officials and administrators can use to predict when the next step will occur. It also briefly discusses how these signs can be used in alternative futures planning, a planning approach designed to enable programs to respond to sudden changes in the communities they serve.

COAL MINING IN THE WEST

Because of the sheer magnitude of all aspects of coal mining as compared with other uses of the same land, such as cattle ranching or wheat growing, a sudden change in the level of mining activity can cause major local disruptions, even under the best of circumstances. The degree of physical modification in surface mining, the size of the construction effort, the transportation system required to move the coal, the number of workers employed, the costs of constructing and operating a mine, and the returns per acre are all at least an order of magnitude greater than for any other use. Any major change in the level of mining activity, therefore, can represent major shifts in every aspect of community life. Some disruption is almost inevitable, but with advance warning of change, adjustments can be made to ease the transition and possibly limit the degree of disruption.

The administration of coal mines in the West is such that it encourages situations where local officials and administrators are not given notice of major changes. Because these officials and representatives of Federal land management agencies have only limited and sharply defined powers to control mining, their powers are concerned primarily with *how* mining is done, not *if* and *when*. For coal mining on Federally-controlled public lands, lease decisions are made in Washington, D.C. But a lease is not a decision to develop a mine at a given time. Ultimately, it is a private mining company that actually decides to change the level of mining activity in an area—to put a mine into production or to

close it down. And it is in the direct financial interest of private mining companies to keep confidential their intentions for as long as possible.

When a mining company first considers an area as a possible mine site, to announce the site could hurt the company in several ways. Other companies might also examine the area to find favorable sites first. Companies would compete for leases and mineral rights. Private individuals holding mineral rights could demand higher prices for these rights. Later, when physical exploration of an area is underway, a company benefits from limiting the amount of information it releases. Information about what the company finds or what level of exploration it will undertake in each location, if released, can help other companies to better predict locations of desirable coal deposits on other lands. Competition with the exploring company and the costs of obtaining mineral rights will increase. The same variables encourage delay in announcing that a mine actually will be developed in a certain location. The cost of planning, which can be large, is another variable that discourages mining companies from announcing precise plans in advance. The sooner construction begins after a mine is planned, the cheaper it is for the company. In fact, the usual procedure is for a mining company to prepare detailed plans only for that portion of the coal deposit to be mined under one mining permit, and to wait until the next permit application to prepare detailed plans for the next section of the coal deposit. Even for a 40-year mine, at any one time the company would have detailed plans only for what it will do in one 5-year period.

Requirements for permits provide local administrators and officials some advance warning that a coal mine is to open. This is not true for a mine closing: the instant a company decides that it is no longer economically wise to continue mining, the company can begin closure. It is in the financial interest of the company to close as quickly as possible once the decision is reached. While the decision is being considered, but before it is actually reached, it is in the company's interest not to release this information. Rumors of the mine closing, or continued uncertainty, can hurt productivity, lower employee morale, affect the value of company stock, and can have a negative influence on the behavior of suppliers and markets with which the company deals.

PREDICTING CHANGES IN MINING ACTIVITY

Because local decisionmakers and Federal representatives must learn to predict changes themselves, the first step is to learn as much as possible about coal mining. What are the steps in coal mining? How is mining actually done? What types of mines are there? Answers to some of these questions are given in the appendix of this report. In addition, the booklet "Anatomy of a Mine" is a thorough treatment of the types and mechanics of mining, and readers are encouraged to send for this booklet. It is available on request to the Director, Intermountain Forest and Range Experiment Station, 507 25th St., Ogden, Utah 84401.

Having obtained a general knowledge of coal mining, the next step is to learn to watch for those conditions that influence the timing of the steps in the development of a coal mine. These conditions are signs that can be used to predict changes in the level of mining activity in an area. Three types of conditions are especially useful for prediction: prerequisites, precludors, and trigger events.

Prerequisites are those conditions or events that *necessarily* occur before a major step in the sequence of mine development may be taken. Some of these prerequisites are merely earlier steps. A potential coal mine developer, for example, would go through several steps before reaching the point at which it would be economically feasible to acquire land rights. These steps would include mapping the land, analyzing its potential to produce coal profitably, meeting legal requirements, and, at least, minimally acceptable social, physical, and economic standards. Prerequisites can be used in two ways to determine when a step in the development of a surface mine will occur. First, as long as the prerequisites for a step have not been fulfilled, that step will not happen. This is useful information by itself, especially if the length of time it takes to complete the prerequisites is known. In this situation, the time period is the minimum length of time before the step can occur. Second, watching the degree of effort mining companies put into fulfilling prerequisites is a good indicator of their intentions.

Precludors are, in a sense, the opposite of prerequisites, but are used in similar ways. A precludor is a condition or event that prevents a major activity or step from happening in the mining development sequence. A substantial decrease in the overall demand for coal, for example, may delay or stop a company, previously interested, from obtaining mineral rights for land overlaying coal. Denial of a permit required before a step can proceed is another example of a precludor.

Trigger events are, perhaps, the most important conditions or events to watch for in predicting when a mine development step will take place. Unlike prerequisites or precludors, which merely allow or prevent a step from taking place, trigger events are those events that help to cause or initiate a major step. They are the stimuli to which those involved in coal mining respond. Some trigger events are linked to changes in demands for coal. A price increase for coal, for example, may make those areas that are economically only marginally feasible for development suddenly become economically attractive. Other trigger events are those that decrease the financial risks of mine development. The discovery of a marketable coal deposit on one tract will almost invariably stimulate physical exploration in surrounding tracts, because the probability of getting a return on exploration costs is higher in these situations. Events that decrease cost of mine development—monetary, political, or environmental—also make mine development more attractive and may initiate the next step in the development sequence.

By identifying, and then watching for, precursors, precludors, and trigger events, those people not involved in coal mining development but affected by it can predict which steps in the sequence of mine development will or will not happen. For the steps that will occur, these indicators can be used to identify when the step will be taken. Often a prediction can be made well in advance of the event.

;IGNS OF CHANGE

Certain steps in the development of a standard coal mine in 'ıe West, along with specific precursors, precludors, and trigger vents, are useful for predicting when or if an event will take 'lace *(Appendix)*.

The steps in the sequence provided were identified by a :view of available literature on surface mine development and 'y questioning knowledgeable people in industry and govern-ıent. The specific procedure involved in locating, securing, nd developing an economically mineable coal reserve may ary considerably throughout the industry depending on the ize, past experiences, and philosophy of the company. It may lso vary from mine to mine depending on the location, physical haracteristics, available information, and legal status of the oal reserve in question. The steps listed are "standard" steps a ıine developer usually must go through. They are given in the rder in which they would most likely be carried out, although ıis is not to imply that a mine cannot be developed without ›llowing these steps, especially in the early planning stages. Vhere not required by law, for example, activities related to nvironmental considerations may or may not be carried out arly in the mine planning process. Where possible, an estimate f the time needed to complete a step is also given, but it must be :cognized that these are only estimates and the actual amount of me may vary significantly because of local conditions.

ιLTERNATIVE FUTURES PLANNING

Learning to predict major changes in the level of coal mining :tivity is one way to reduce the disruption resulting from these ıanges. Another way is for local officials and administrators to lopt planning and management approaches that both prepare ıem and leave them the flexibility needed to deal with major, npredicted changes. Alternative futures planning is one such ɔproach (Thor 1979).

In alternative futures planning, a wide range of possible ıtures are considered and examined. The local official or ad-ıinistrator determines how to deal with each of these futures, ıd, very importantly, how the activities for one future could ffect a response to another. This helps identify key decisions 'hich, once made, foreclose important options. Often these key ecisions do not have to be made for some time, and only additional planning practices have caused them to be made ırly. In alternative futures planning the timing of when these ecisions must be made to respond to different futures is iden-fied. Sometimes a decision is put off until later in the belief that ıis delay will lead to a better decision because of additional ıformation. Other decisions, if made promptly, however, will pen up future options and the decisionmaker's ability to re-ɔond to different futures. Alternative futures planning iden-fies these for prompt action. The result of alternative futures planning is a course of action for the near future, and a description of key decisions to be made at another time. This description includes what the choices are, what assumptions and information will probably be needed to make the decision, and when or under what conditions each decision must be made.

The *first step* in alternative futures planning is the preparation of a relatively small number of written scenarios describing possible futures for the planning area. Each scenario provides a brief picture of one possible long-term future, and is centered generally around major trends or events largely outside the control of the local official or administrator. The discovery and development of a large coal field in an area, for example, could be one such event. Other scenarios could be built around different possible court rulings on water rights and Federal land, massive, synthetic fuel developments supported by the Federal government, or on the States gaining control of Federally-managed public land. The final stage in preparing the scenarios is to identify key issues and demands for each scenario that define the management problem facing the local official or administrator, if that scenario were to occur. What would each agency have to do in the case of a boom-town, a flood of exploration permit applications, or the closing of a mine? Because the remainder of the planning process is aimed at responding to these management problems, it is essential that issues and demands are identified carefully.

Having identified the management problem for each scenario, the *second step* is to determine the official's or administrator's capability to respond to these problems. What resources would be available under each scenario? What physical, legal, social, or economic limitations would be placed on their use? Where this information is not readily available, inventories and information collection efforts must be undertaken. Local officials may want to prepare lists of persons and agencies to turn to for help, or of actions taken by other officials and towns in similar situations. Once this information is assembled, it is analyzed to assess the range of feasible actions the manager could take, how these actions would help to alleviate the management problem, and any special limitations on these actions.

The *third step* in alternative futures planning is to determine the goals, objectives, and decision criteria that will control the development of the plan and the choice among alternatives. These are developed on a scenario-by-scenario basis in terms of the issues and demands, and the capability to respond to those issues within each scenario. One objective, for example, could be to be sure that no retired persons are forced out of their homes by higher prices and taxes in the event of a boom-town situation. Second, additional goals, objectives, and decision criteria are developed that allow a comparison between scenarios. This is where relative values are established for meeting a particular objective under one scenario as opposed to meeting another objective under a different scenario. Some of these additional goals, objectives, and decision criteria provide guidance for what to do when the aims and emphases are different or conflicting between scenarios. Others address the acceptable degree of risk that the objectives of a particular scenario will not be met, if that scenario occurs. Local agencies, for example, may be willing to risk crowding of the local schools, rather than to pay for schools that may not be needed. These same agencies,

however, may be willing to put considerable time and expense into assuring that the agricultural water supply will not be cut off.

These second and third steps do not occur in strict chronological order, but instead, there is cycling and feedback. It is necessary to have a good idea of what actions are possible before goals, objectives, and decision criteria for choosing among these actions can be developed. Much of step two, therefore, must be completed before step three. At the same time, however, efficient gathering of information requires knowledge of what questions the information will be used to answer. For planning, the description of the official's or administrator's ability to respond to management problems must be expressed in terms compatible with the goals, objectives, and decision criteria used to evaluate those reponses. To assure that the correct information is available and time is not wasted gathering unnecessary information, the goals, objectives, and decision criteria should be largely developed before any expensive inventory or feasibility study is undertaken.

The *fourth step* in alternative futures planning is to identify the cross impacts of different activities. The decisionmaker examines how actions taken to respond to one scenario's management problem would affect his ability to take actions appropriate to other scenarios. If one type of sewage treatment plant is built for a small local population, for example, can it be expanded to handle a large boom-town situation? Key decisions are identified that either foreclose potentially important options once they are made or create options if made promptly. Particular attention is given to the order in which actions can occur and when the decision to take these required actions must be made if they are to have the desired result.

The *fifth step* in alternative futures planning is to isolate events and conditions that can be used in the future to determine which scenario will occur or is occurring. It is here that precursors, precludors, and trigger events are identified. For coal mining scenarios the precursors, precludors, and trigger events from the *Appendix* can be used, or modified to fit local conditions.

The *sixth step* is the choice of "the" plan to be followed by the decisionmaker and staff, using all of the information generated in the preceding steps. In some respects this plan is like any other management plan to determine programs and lay out a course of action for the immediate future that will accomplish the overall goals and objectives. In addition to management activities for the immediate future, however, the plan specifies key decisions that are not to be made at this time because the benefits of making a commitment are outweighed by possible costs of being unable to respond to one of the future scenarios as a result of making these decisions early. The plan indicates what the choices are, the decisions, when or under what conditions they need to be made, and what information or assumptions will probably be needed to make the decisions. It also lists prerequisites, precludors, and trigger events to be watched for in assessing which scenarios will occur and, therefore, which alternative actions should be taken. The plan might indicate, for example, that the local District Manager of the Bureau of Land Management or the Forest Supervisor of the Forest Service should watch the filing of deeds for mineral rights on adjacent private lands. When a sudden increase in filing of deeds occurs, the manager or supervisor should follow the portion of the plan that responds to a future of coal mining development. The plan usually includes a request for a minerals specialist, additional staff, and clerical support in the manager's or supervisor's next program, and, a budget request to process all of the permit applications that are likely. (Note that an initial budget request often must be made 3 years in advance of when the money is needed and, therefore, early action is essential.) The plan also indicates the basic assumptions that must hold and the events that can or cannot happen for the current plan to be valid. This is an indicator of when the plan must be updated.

The general procedure for choosing the plan is the same as that used in any decision process: alternatives are developed, evaluated, and the one alternative that best meets the overall goals, objectives, and decision criteria is selected. How this is done specifically depends on the degree to which analytical decision aids are used. At one extreme, general management rules are developed and followed, such as: delay those decisions that remove the most options as long as possible, take special care to maintain flexibility in the use of those resources needed to reach the most difficult objective under each scenario, or take those actions common to all scenarios first. At the other extreme, the plan can be selected through the use of optimization techniques, such as stochastic programing that incorporates the uncertain future and cross-impacting actions into a mathematical solution.

The *final step* of alternative futures planning is repeated for as long as the plan is in effect. This step includes carrying out the actions and making the decisions identified in the plan, and amending or revising the plan. A minor revision is made when it is determined that one of the scenarios is occurring, or the probability of the different scenarios occurring has changed. On the basis of the additional information, more refined management direction is developed. Where the plan states, "If this happens we will do so and so," the revision states, "This is happening, with minor modifications, perhaps and, therefore, this part of the plan will be implemented and other parts downplayed." A major modification of the plan is necessary when it becomes apparent that none of the scenarios described in the original plan is occurring and, therefore, a new plan must be developed.

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APPENDIX:

SEQUENCE OF COAL MINE DEVELOPMENT

Definitions:

Prerequisite
An event that *necessarily precedes* the major activity.

Precludor
An event that most likely would *prevent* the major activity from occurring.

Trigger event
An event which, if it occurs, *may initiate* the major activity.

Land and Mineral Rights Obtained

- Surface and mineral ownership of reserve area mapped by mining company.
- Cursory environmental, economic, and geologic analyses favorable.
- Mining company landperson contacts private holders of surface and mineral rights; lease or purchase, or contract with option to purchase negotiated (Stroud 1976)
- If Federal land involved, lease obtained from Bureau of Land Management—minimum 2 years to lease award (U.S. MPERC 1977)

- Decreased demand for coal because of decrease in overall demand for energy or development of alternate energy technology
- Change in technology resulting in decreased demand for rank of coal on land under consideration.
- Change in tax rules, government allowances, or environmental protection standards unfavorable to industry
- Leasing or private land acquisition process takes overly long, mining company loses interest because of acquisition of better lands, lack of funds, loss of potential market, and other reasons
- Tracts of land essential to complete a logical mining unit cannot be leased or purchased because of private landowner holdouts (Stroud 1976), specific legislation prohibits mining on certain Federal lands.
- Environmental problems identified which make mining impractical
- Bureau of Land Management does not approve essential lease, or lease goes to alternate bidder.

- Market for and/or price of coal increase(s).
- Federal coal leasing program begins.
- Change in tax rules, government allowances, or environmental protection standards favorable to industry.
- Improved mining or reclamation technology developed.
- Improved public attitude toward strip mining because of severe energy shortage, major accident involving an alternate source of energy, observation of successful reclamation, or improved technology.
- Eminent domain rights extended to coal slurry pipelines; areas where rail, truck, or boat transport of coal was economically not feasible now become feasible to mine (Guccione 1978).
- Increasingly stringent sulfur dioxide (SO_2) emissions standards make Western low sulfur coal more competitive.
- Development of competitive coal to synthetic fuel conversion industry (Cochran 1976).
- Bid request received from potential customer (Jones 1977).
- Mining company looking for available reserve while seeking a market (Jones 1977).

Physical Exploration

(Time estimate: from 6 to 18 months to completion)

- Federal lease and or State private drilling rights obtained
- Literature search to determine geology, previous discoveries, and access routes completed; information mapped on base maps or aerial photos.

- Equipment or personnel not available.
- Preliminary information obtained from literature and field shows area to be highly unfavorable.
- Lease application denied.

- Significant coal deposit discovered.

Personal communication from Jon M. Cassady, Amax Coal Company, Indianapolis, Ind., August 30, 1978

[2] Personal communication from James R. Jones, Peabody Coal Company, St. Louis, Mo., July 18, 1978

Prerequisite	Precludor	Trigger event
• ompletion of geological reconnaissance (may ·quire use of airplane or helicopter) to select best ›cations for detailed geological studies (U.S. ep. Int. 1977).	• Drilling rights not obtained.	
• xploration plan designed.	• Regulatory agency does not approve proposed exploration and reclamation operations. Agency has determined operations will: a. Not be conducted in accordance with the coal exploration performance standards specified in 30 CFR Ch. 7, Pt. 814, Subch. K; b. Adversely affect an endangered or threatened species listed pursuant to Section 4 of the Endangered Species Act of 1973 (16 USC Sec. 1531); c. Adversely affect any object listed on the National Register of Historic Places unless ap proved by agency with jurisdiction.	
• or coal operations in which less than 250 tons of ›al are removed in any one location, notice of tention to explore filed with regulatory agency ;0 CFR Ch. 7, Pt. 776.11(a)).	• Other permits denied.	
• or coal operations in which more than 250 tons ' coal are removed: application for approval led with regulatory authority, public notice ven in vicinity of proposed exploration area, ›plication approved by regulatory agency, and ›tice placed in newspaper of general circulation vicinity (30 CFR Ch. 7, Pt. 776.11b).	• Litigation in progress against mining operations	
• ther licenses and permits obtained as necessary, ›r example, FCC special radio operator license, AA landing tower and strip license, IRS explo- ve user's and/or manufacturer's license, sur- ce management agency right of way permit J.S. MPFRC 1977).		
• erformance bond posted (30 CFR Ch. 7, Pts. 42 and 802).		
• rilling and construction bids released and con- acts awarded.		
• eld office established (Springman 1977).		
• ccess roads and buildings completed.		
• rilling equipment and personnel arrive on site.		

itial Environmental Reconnaissance

(ne estimate: 30 days)

Prerequisite	Precludor	Trigger event
• iterature search for existing environmental in- ›rmation completed.		• Exploratory drill rigs confirm existence of marketable coal.[2]
• xploration underway.		• Concern over environmental effects of mining this site expressed by some segment of public
• ompany has qualified personnel or contracts for ·ork.		

:onomic Analysis, Feasibility Assessment

Prerequisite	Precludor	Trigger event
• esults of drilling program analyzed, reserve is :termined to be commercially mineable and arketable (Jones 1977).	• Delays in analysis of drilling data; insufficient data to make decision.	• Company has potential market for coal.
• itial environmental reconaissance of area re- lts in favorable environmental report (Jones)77).	• Environmental report indicates serious environmental constraints or possible impacts that would be difficult to mitigate; unlikely company can mine economically and stay within government regulations.	
• eliminary mining plan designed; in-house in- :ntory of available equipment (Pentz 1977).	• Inability to develop economical transportation to market.[3]	

[1] Personal communication from James R. Jones, Peabody Coal Company, St. Louis, Mo., September 11, 1978.

Prerequisite | **Precludor** | **Trigger event**

Identification of Potential Customer

- Market survey done by company (Jones 1977).
- Data from drilling program analyzed for needs of customer (Jones 1977).

- No customers available because of:

  a. Rapid increase in local or regional coal prices,

  b. Reduction in local or regional prices of alternate energy source, or

  c. Inaccurate market survey.

- Bid request received from potential customer.

Environmental Assessment Report

- Positive feasibility decision made.
- Field program for environmental assessment designed—15 to 30 days (U.S. Senate 1977).
- Consultant selection if needed (Jones 1977)—4 to 6 weeks.[4]
- Baseline environmental and geological data, engineering information collected, contour maps completed—1 year (U.S. Senate 1977).[2]
- Report assembled into required format—90 days.[2]

Detailed Project Design

- Positive feasibility decision made.
- Baseline environmental data collected.
- Best future use of land determined.

- Contacts with contractors, equipment manufacturers, labor unions (Springman 1977).
- Frequent contacts with local planners, other government agencies.

Application for Mining Permit Submitted

- Environmental assessment report completed and favorable.
- Mining and reclamation plans designed.
- Board of Directors of mining company makes development commitment (Springman 1977).
- Market for coal identified (U.S. Senate 1977) and details of customer's needs known (Jones 1977).
- Surface rights secured.
- Mine Safety and Health Enforcement Administration contacted for mine identification number—2 to 3 days.[5]

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[4] Personal communication from Catherine Pahl, Dames and Moore, Denver, Colo., July 13, 1978.

[5] Personal communication from Rita Weaver, Mine Safety and Health Admin., Health & Safety Analysis Center, Denver, Colo., August 4, 1978.

Prerequisite	Precludor	Trigger event

Mining Permit Issued

Prerequisite	Precludor	Trigger event
Mining permit approved by regulatory agency—60 or more days (U.S. Senate 1977). Performance bond post (30 CRF Ch. 7, Pts. 800.11 and 742.12).	• Litigation. • Permit denied, hearing requested, 30 days to advertise hearing, 30 days for agency to respond (U.S. Senate 1977). • Mining plan found to include areas designated unsuitable for mining under 30 CFR Ch. 7, Subch. F. Such areas are defined as: a. On any lands within boundaries of, or adjacent areas necessary to prevent impacts on, the National Park System, National Wildlife Refuge System, National System of Trails, National Wilderness Preservation System, Wild and Scenic Rivers System, and National Recreation Areas. b. On any Federal lands within boundaries of any National Forest except where the Secretary of the Interior determines there are no significant recreational, timber, economic, or other values incompatible with surface mining and the Secretary of Agriculture determines that on lands which do not have significant forest cover west of the 100th meridian, mining operations comply with Multiple Use Sustained Yield Act 1960, 1975 Federal Coal Leasing Amendments, and 1976 National Forestry Management Act. c. Where mining operations would adversely affect any public park or any places included on, or eligible for listing in, the National Register for Historic Places unless otherwise approved by both the Federal, State, or local jurisdiction over the park or historic place and the regulatory authority. d. Within 100 feet of the outside right-of-way line of any public road except where mine access or hauling roads join the right of way or the regulatory authority allows the road to be relocated or determines landowners' interests will be protected. e. Within 300 feet of any occupied dwelling unless owner has provided a written waiver. f. Within 300 feet of any public building or park, school, church, community, or institutional building. g. Within 100 feet of a cemetery. h. Unsuitable under State or Federal regulatory programs.	

Arrange for Labor

Prerequisite	Precludor	Trigger event
Permits issued or no problems foreseen.[6] Heavy equipment arrangements made.[6]	• Delay in permit approval process. • Delay foreseen in heavy equipment arrival, or manufacturer not able to supply equipment ordered.	• Construction materials arrive.

[6] Personal communication from Dale Burgaard, nax Coal Company, Denver, Colo., July 19, 1978.

Ferrante, Lynn M., and Edward C. Thor.

1980. **Predicting events in the development of a coal surface mine in the West**. Gen. Tech. Rep. PSW-41, 11 p. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

Sudden changes in the level of coal mining activity in an area can cause immediate and profound changes in every facet of life in a rural community. Local officials and administrators of Federal and State governments often bear the brunt of responding to the disruptions that result from these changes. The nature of coal mining in the West is such that the community in general and the resource managers and officials involved often do not receive sufficient warning of the changes in mining and so are caught unprepared. By learning what signs to look for, however, these decision makers can preduct such changes and thereby be prepared to deal with them.

Retrieval Terms: rural environment, change agents, community change, prediction, strip mining, surface mining

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Agriculture

Forest Service

Pacific Southwest
Forest and Range
Experiment Station

General Technical
Report PSW-42

Economic Data for Wildland Planning and Management in the Western United States: A Source Guide

Eric Eisenman Lee C. Wensel Edward C. Thor Thomas W. Stuart

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CONTENTS

Economic facts and figures are needed for sound planning and management of forests and rangelands. Sometimes he information needed may not have been collected; all too ften, however, it is available but remains unused because sers do not know where to locate the data. Tracking down the lata is not easy. The facts and figures are contained in publicaions, internal reports, newsletters, computer data bases, file abinets, and personal notes. These resources are produced or naintained by a wide variety of Federal, State and local overnment agencies; public and private universities; and priate organizations, such as public interest groups, trade assoiations, and corporations which gather and sell data. To ompound the problem, these agencies and organizations are cattered throughout the country.

This report provides sources of economic facts and figures seful in planning and managing forest and rangelands in the Vestern United States. It culminates extensive efforts in dig;ing through libraries, phone calls, correspondence, and pourng over anything that might be remotely related to our project. hrough this search we have identified sources of general conomic and social data, as well as sources of data for nalyzing six major management activities: (a) outdoor recreaion and wilderness, (b) wildlife and fish, (c) range, (d) timber, e) land and water, and (f) minerals and energy. Under each of he six activity groupings, data sources are identified as folows: costs of management activities, outputs and their moneary values, nonmonetary data and impacts, information for upply and demand analysis, and secondary and indirect ffects.

This guide contains data sources which were judged to be oth available and of broad audience value. There are unoubtedly useful sources of facts and figures which we missed. he "Additional Data Sources" section is an aid in searching for data sources beyond those included here. This section contains descriptions of other directories and organizations which tell where to locate data on a variety of subjects. The Appendix contains addresses of relevant Federal and State agencies.

HOW TO USE THIS GUIDE

This report has several distinct sections, and three different coding systems. Understanding the purpose of each, and how they are related, will greatly increase your ability to easily locate desired facts and figures.

The main sections of this report are a *Subject Guide*, a listing of *Data Sources and Descriptions*, a listing of *Additional Data Sources*, an *Appendix* with a directory of agencies, and an *Index*. The *Subject Guide* and listing of *Data Sources and Descriptions* comprise the bulk of this report.

The *Subject Guide* lists seven categories of economic data useful for planning and management of wildland areas (see the table of contents for an overview of the categories and the coding system). The listing is hierarchical, with each category broken into more detailed subcategories. For example, "range management" is a main category. The first subcategory under this heading is "cost of management activities" which is further divided into seven subcategories. For some topics, third-level subcategories are included if warranted. Each category and subcategory is identified by a numeric code to help locate topics. For example, all range topics are in the 400 series. The "costs of management activities" category is code 410, and the subcategory, "range structural improvements," is code 417.

The *Subject Guide* identifies categories and data resources germane to these categories. Each category contains a list of relevant data sources by code number. These coded ID numbers are then used to locate the data source descriptions in the section following the subject guide.

The ID number is in two parts. First, a two-letter code identifies the supplier of the data source:

Organization
code:

AK	Alaska State Government
AZ	Arizona State Government
CA	California State Government
CO	Colorado State Government
CU	Colleges and Universities
HI	Hawaii State Government
ID	Idaho State Government
MT	Montana State Government
NE	Nebraska State Government
NM	New Mexico State Government
NV	Nevada State Government
OR	Oregon State Government
PR	Private Organizations
SD	South Dakota State Government
US	United States Government
UT	Utah State Government
WA	Washington State Government
WY	Wyoming State Government

Thus, ID numbers for all sources supplied by the U.S. Government begin with the letters US; where a State government agency is the supplier, the ID starts with the two-letter postal abbreviation for that State. Following the two-letter code is a three-digit number, sequentially numbered, starting at 501. Governmental agencies are an exception because on request they can often supply specific data and advice separate from published reports and formal data files they maintain, and therefore have been designated with a separate sequence beginning at 800. Computer tape sources are a second exception and start at 900. The sample subject entry below provides data sources for net timber volume statistics.

```
531 Timber inventories

    531.1 Net volume
          CO-502  CU-501  CU-508  CU-510
          CU-520  CU-531  HI-501  ID-802
          MT-501  NM-502  NM-801  PR-527
          US-501  US-503  US-505  US-506
          US-533  US-534  US-535  US-536
          US-537  US-541  US-544  US-555
          US-556  US-579  US-596  US-624
          US-625  US-626  US-627  US-633
          US-637  US-640  US-642  US-643
          US-653  WA-506
```

The first source identification code, CO-502, is the secon source listed on the CO section, and is supplied by an agenc of the Colorado State Government. To find information abo this data source, look in *Data Sources and Descriptions* und CO-502.

Data Sources and Descriptions contains listings and d scriptions of data sources referred to in the subject guide. Da sources are organized alphabetically, and then numerically b identification code. Thus, all NE (Nebraska) entries com before NM (New Mexico) entries, but after MT (Montana Whenever possible, the description of each data source i cludes a contents summary, address where the source can b obtained, frequency of information updating, and compani sources. When contents summaries were derived from seco dary sources, they are cited as such. Contents summaries fro the data source itself are indicated by quotation marks and r citation.

The *Additional Data Sources* section describes biblio raphies, statistical reference services, information exchange directories, and other guides to additional data sources. Th *Appendix* contains the addresses and commercial telepho numbers of key Federal and State agencies related to plannir and management of forests and rangelands in the Weste United States. These two sections can be used as the starti point for further searches when desired data cannot be fou using this guide.

UBJECT GUIDE

0 *General Economic and Social Impacts*

Employment

1 Employment figures

111.1 Total employed

AK-501 AK-503 AK-504 AK-506
AK-507 AZ-502 CA-501 CA-502
CA-506 CO-803 CU-501 CU-502
CU-503 CU-504 CU-505 CU-506
HI-501 HI-503 ID-803 MT-501
MT-502 MT-508 MT-509 NE-501
NE-801 NM-504 NV-501 NV-506
OR-505 PR-501 PR-502 PR-503
PR-514 SD-501 SD-802 US-501
US-526 US-529 US-545 US-546
US-547 US-548 US-549 US-550
US-554 US-560 US-589 US-592
US-604 US-606 US-615 US-623
US-628 US-636 US-641 US-807
US-902 US-906 UT-502 WA-501
WA-511 WY-501 WY-507

111.2 Unemployed

111.2a Total

AK-503 AK-506 AK-507
AZ-502 CA-502 CO-803
CU-501 CU-502 CU-504
CU-505 CU-506 HI-501
ID-803 MT-501 MT-508
MT-509 NE-501 NE-801
NV-501 PR-501 PR-503
SD-501 US-501 US-526
US-545 US-546 US-547
US-548 US-589 US-604
US-606 US-615 US-641
US-807 US-906 WA-501

111.2b Rate

AK-503 AK-506 AK-507
AZ-502 CO-803 CU-501
CU-504 CU-505 CU-506
HI-501 ID-803 MT-508
MT-509 NE-501 NE-801
NV-501 PR-501 US-501
US-502 US-554 US-589
US-606 US-615 US-641
US-807 WA-501

2 Employment structure

112.1 Number of employers by occupation or industry

AK-504 CA-506 CO-803 HI-501
HI-503 ID-803 MT-501 NE-801
NM-504 NV-506 OR-505 PR-501
PR-503 SD-802 US-616 US-621
US-622 US-628 US-903 US-908
US-909 UT-502 WA-511 WY-507

112.2 Number of employees by occupation or industry

AK-501 AK-503 AK-504 AK-506
AK-507 AZ-502 CA-501 CA-506
CO-803 CU-501 CU-502 CU-504
CU-505 CU-506 CU-507 CU-531
CU-532 HI-501 HI-503 ID-803
MT-501 MT-502 MT-508 MT-509
NE-501 NE-801 NM-504 NV-501
NV-506 OR-505 PR-501 PR-502
PR-503 PR-514 PR-515 PR-516
PR-519 PR-527 PR-533 SD-501
SD-802 US-501 US-502 US-503
US-524 US-529 US-532 US-535
US-546 US-547 US-548 US-550
US-580 US-581 US-589 US-592
US-604 US-606 US-614 US-615
US-621 US-622 US-623 US-628
US-643 US-807 US-902 US-903
US-906 US-908 US-909 WA-501
WA-503 WA-511 WY-501 WY-507

112.3 Income structure/wage rate, by occupation or industry

AK-501 AK-503 AK-506 AZ-502
CA-501 CO-803 CU-501 CU-502
CU-505 CU-506 CU-507 HI-501
MT-501 MT-509 NE-501 NV-501
PR-501 PR-503 PR-515 PR-516
PR-519 SD-501 US-501 US-529
US-532 US-535 US-546 US-547
US-548 US-549 US-592 US-604
US-606 US-615 US-616 US-641
US-807 US-902 US-904 US-906
UT-502

113 Payrolls by occupation or industry

AK-504 AK-506 AK-507 CA-506
CO-803 CU-531 HI-503 ID-803
MT-502 NE-801 NM-504 NV-506
OR-505 SD-802 WA-511 WY-507

114 Labor productivity

PR-533 US-501 US-546 US-548
US-554 US-616 US-623 US-659
US-807

120 Population

121 Total population

121.1 Present figures

AK-501 AK-506 AK-507 CA-501
CU-501 CU-502 CU-503 CU-504
CU-505 CU-506 HI-501 MT-501
MT-502 NE-501 NV-501 PR-501
PR-502 PR-503 PR-504 SD-501
US-501 US-502 US-550 US-551
US-553 US-559 US-560 US-589
US-604 US-606 US-615 US-623
US-636 US-641 US-906 WA-501
WY-501

121.2 Projections

AK-506 CU-505 CU-506 HI-501
MT-501 NE-501 PR-501 PR-502
PR-503 US-501 US-550 US-551
US-553 US-560 US-589 US-615
US-636 US-641 US-650

122 Population composition and structure

122.1 Population of minority groups

AK-501 CU-502 CU-505 HI-501
MT-501 MT-502 NE-501 PR-501
PR-502 PR-503 US-501 US-502
US-589 US-604 US-606 US-615
US-641 US-906 WA-501

122.2 Population by age groups

CU-501 CU-502 CU-503 CU-504
CU-505 CU-506 HI-501 MT-501
MT-502 NE-501 NV-501 PR-501
PR-502 PR-503 PR-504 SD-501
US-501 US-502 US-589 US-604
US-606 US-615 US-623 US-641
US-906 WA-501 WY-501

122.3 Population by sex

CU-501 CU-504 CU-505 CU-506
HI-501 MT-501 MT-502 NE-501
NV-501 PR-501 PR-502 PR-503
SD-501 US-501 US-502 US-589
US-604 US-606 US-615 US-641
US-906 WA-501 WY-501

122.4 Population density

CU-501 CU-502 CU-505 CU-506
HI-501 NE-501 PR-501 PR-502
US-501 US-502 US-606 US-636
WA-501

123 Population changes

123.1 Absolute change

AK-501 AK-507 CA-501 CU-503
CU-504 CU-505 CU-506 HI-501
MT-501 MT-502 NE-501 PR-501
PR-502 PR-504 SD-501 US-501
US-502 US-604 US-606 US-615
US-641 WA-501

123.2 Percent change

AK-501 CA-501 CU-503 CU-504
CU-506 HI-501 MT-501 MT-502
NE-501 PR-502 PR-504 SD-501
US-501 US-502 US-615 US-636
US-641 WA-501

123.3 Change components

123.3a Births

AK-507 CA-501 CU-501
CU-502 CU-503 CU-504
CU-505 CU-506 HI-501
MT-501 MT-502 NE-501
NV-501 PR-501 PR-502
PR-503 SD-501 US-501
US-502 US-606 US-615
US-623 US-641 WA-501
WY-501

123.3b Deaths

AK-507 CA-501 CU-501
CU-502 CU-503 CU-504
CU-505 CU-506 HI-501
MT-501 MT-502 NE-501
NV-501 PR-501 PR-502
PR-503 SD-501 US-501
US-502 US-606 US-615
US-623 US-641 WA-501
WY-501

123.3c Migration and migration patterns

AK-501 CA-501 CU-502
CU-503 CU-504 CU-506
HI-501 MT-501 NE-501
NV-501 PR-502 PR-503
SD-501 US-501 US-502
US-592 US-606 US-615
US-623 US-641 US-902
WA-501

130 Income

131 Personal income

AK-506 AK-507 CA-501 CA-502
CU-501 CU-502 CU-503 CU-504
CU-506 HI-501 MT-501 MT-502
MT-508 NE-501 PR-501 PR-502
PR-503 PR-504 SD-501 US-501
US-505 US-526 US-529 US-550
US-551 US-553 US-554 US-558

US-559 US-560 US-589 US-604
US-606 US-615 US-623 US-636
US-641 US-668 US-669 US-904
US-906 UT-502 WA-501 WY-501

Distribution Figures

132.1 Family income
AK-501 CU-502 CU-504 CU-505
CU-506 HI-501 MT-501 MT-502
PR-502 SD-501 US-501 US-502
US-505 US-604 US-606 US-615
US-623 US-641 US-668 US-669
US-906

132.2 Per capita income
AK-501 AK-507 CU-501 CU-502
CU-503 CU-504 CU-505 CU-506
HI-501 MT-501 NE-501 PR-501
PR-502 PR-503 PR-504 SD-501
US-501 US-505 US-550 US-551
US-553 US-559 US-560 US-589
US-606 US-615 US-623 US-636
US-641 US-668 US-669 US-904
UT-502 WA-501 WY-501

132.3 Population or families below the poverty level
AK-501 CU-502 CU-504 CU-505
MT-501 PR-502 SD-501 US-501
US-502 US-589 US-604 US-606
US-615 US-641 US-906

Housing

Number of units

141.1 Total units
CU-501 CU-502 CU-503 CU-504
CU-505 CU-506 HI-501 MT-501
MT-502 NE-501 PR-503 SD-501
US-501 US-502 US-506 US-527
US-578 US-604 US-606 US-615
US-906

141.2 Single family homes
CU-503 CU-506 HI-501 US-501
US-527 US-578 US-604 US-906

141.3 Multiple dwellings/apartments
CU-503 HI-501 US-527 US-578
US-604 US-906

141.4 New housing units
AK-507 CA-501 CA-502 CU-502
HI-501 MT-501 MT-502 NE-501
PR-501 PR-503 PR-505 PR-514
PR-515 PR-527 US-502 US-506
US-524 US-526 US-529 US-558
US-578 US-606 US-633 WA-503
WY-501

141.5 Vacant dwellings

141.5a Number
CU-501 CU-503 CU-504
CU-506 HI-501 MT-501
MT-502 NE-501 SD-501
US-501 US-502 US-506
US-527 US-578 US-604
US-906

141.5b Rate
HI-501 MT-501 NE-501
US-501 US-502 US-524
US-526 US-527 US-578

142 Housing prices

142.1 Construction costs
US-524 US-526

142.2 Price indexes
AK-507 SD-501 US-501 US-546
US-547 US-606

142.3 Value of new housing units
PR-503 US-501 US-524

142.4 Value of all housing
US-501 US-527

142.5 Monthly housing costs
US-527

150 Government Revenues

151 Tax revenues

151.1 Property tax
AK-507 CA-501 CU-502 CU-503
CU-505 HI-501 MT-501 MT-502
NV-501 PR-501 PR-502 PR-503
PR-504 SD-501 US-501 US-502
US-516 US-517 US-518 US-520
US-521 US-522 US-606 WA-501
WY-501

151.2 Sales tax
AK-507 CU-501 CU-504 CU-506
MT-501 MT-502 PR-501 PR-503
PR-504 SD-501 US-501 US-516
US-518 US-519 US-520 US-521
US-522 US-606 WY-501

151.3 Income taxes
AK-507 CU-505 CU-506 HI-501
MT-501 PR-503 US-501 US-516
US-520 US-606

151.4 Others
AK-507 CU-501 CU-504 CU-505
CU-506 HI-501 MT-501 MT-502
PR-501 PR-502 PR-503 PR-504
US-501 US-516 US-517 US-518
US-519 US-520 US-521 US-522
US-606 WY-501

152 Intergovernmental revenue (aid, grants, subsidies, etc.)
AK-507 CU-502 CU-506 CU-531
HI-501 MT-501 MT-502 PR-502
PR-503 PR-504 SD-501 US-501
US-517 US-519 US-520 US-521
US-522 US-605 US-606 US-672
US-805 WA-501 WA-510

152.1 Federal revenue sharing
CU-502 CU-531 MT-502 PR-502
PR-503 SD-501 US-517 US-518
US-519 US-520 US-521 US-522
US-605 US-606 US-672 US-805
WA-501 WY-501

152.1a U.S. Forest Service sharing of receipts
CU-531 PR-504 US-501
US-505 US-605 US-606
US-805

153 Receipts from lands (see specific resources, Outputs and Their Monetary Values)

154 Others
AK-507 CU-502 PR-502 PR-503
SD-501 US-518 US-519 US-520
US-521 US-522 US-576 US-606
WY-501

160 Services

161 Government expenditures, by function

161.1 Education
AK-501 AK-507 CA-501 CU-502
CU-503 CU-504 CU-505 CU-506
HI-501 MT-501 NE-501 PR-502
PR-503 SD-501 US-501 US-502
US-518 US-519 US-520 US-521
US-522 US-606 WA-501 WY-501

161.2 Law enforcement
AK-507 CU-502 CU-503 CU-504
CU-506 HI-501 MT-501 PR-502
PR-503 PR-504 SD-501 US-501
US-502 US-518 US-519 US-520
US-521 US-522 US-606

161.3 Fire protection
AK-507 CU-503 CU-506 HI-501
PR-502 PR-504 US-501 US-502
US-519 US-520 US-521

161.4 Recreation and parks
CU-503 CU-506 HI-501 PR-50
US-501

161.5 Public utilities, water, sew
maintenance and sanitation
AK-501 AK-507 CA-501 CU-50
CU-505 CU-506 HI 501 NE-50
PR-502 PR-503 US-501 US-50
US-519 US-520 US-521

161.6 Roads
AK-507 CA-501 CU-503 CU-50
CU-505 PR-502 PR-504 US-50
US-502 US-512 US-606 WA-50

161.7 Welfare and public aid
AK-507 CU-501 CU-502 CU-50
HI-501 MT-501 NE-501 PR-50
PR-503 SD-501 US-501 US-51
US-519 US-520 US-521 US-52
US-606 WA-501 WY-501

161.8 Health and medical facilitie
AK-507 CA-501 CU-504 CU-50
MT-501 PR-502 PR-503 PR-50
SD-501 US-501 US-502 US-51
US-518 US-521 US-522 US-60
WA-501

161.9 General government and other
AK-507 CU-502 CU-503 CU-50
CU-506 HI-501 MT-501 MT-50
PR-502 PR-503 PR-504 SD-50
US-501 US-518 US-519 US-52
US-521 US-522 US-554 US-60
WA-501 WY-501

162 Private service activities

162.1 Retail trade
CA-501 CU-502 CU-503 CU-50
CU-505 CU-506 HI-501 MT-50
MT-502 NE-501 PR-501 PR-50
US-526 US-554 US-558 US-60
US-622 US-909 WA-501

162.2 Wholesale trade
CA-501 CU-502 CU-503 CU-504
CU-505 CU-506 HI-501 MT-501
MT-502 NE-501 US-606 US-621
US-908 WA-501

) Other General Economic and Social Data

1 Multiplier values
CU-530 US-557 US-655

2 Input-output data
CU-530 US-594 US-808 US-905

0 *Outdoor Recreation and Wilderness*

Costs of Management Activities

1 Cultural resource management
US-815

2 Visual resource

212.1 Improvement
US-815

212.2 Inventory and planning
US-815

3 Recreation or visitor information
rvices sites

213.1 Construction
US-815

213.2 Rehabilitation
US-815

4 Visitor information services

214.1 Planning
US-815

214.2 Full service management
US-815

214.3 Reduced service management
US-815

5 Installation or construction of
sitor information services facilities
t on visitor information service site
CU-509 US-815

6 Developed recreation sites

216.1 Full service management public sector
US-815

216.2 Reduced service management-public sector
US-815

217 Dispersed recreation

217.1 Full service management
US-815

217.2 Reduced service management
US-815

218 Recreation management (private and other public sector)
US-815

219 Wilderness areas

219.1 Planning and inventory
US-815

219.2 Full service management
US-815

219.3 Reduced service management
US-815

See also Income structure/wage rate (112.3)

220 Outputs and Their Monetary Values

221 Use levels (visitor days and/or number of participants)
AK-505 AK-802 AZ-501 AZ-801
CA-503 CA-505 CA-801 CA-802
CU-502 CU-512 CU-514 CU-518
CU-528 CU-531 HI-502 ID-502
ID-801 MT-504 MT-505 NE-502
NE-503 NM-803 NV-502 NV-503
NV-801 OR-801 PR-503 PR-524
PR-525 PR-528 PR-901 PR-902
SD-502 SD-801 US-501 US-512
US-523 US-530 US-561 US-562
US-569 US-573 US-575 US-586
US-587 US-589 US-595 US-605
US-606 US-615 US-636 US-657
US-801 US-803 US-804 US-805
US-811 US-815 US-901 UT-802
WA-501 WA-504 WA-801 WY-501
WY-502 WY-505

221.1 By activity

AK-505 AZ-501 CA-801 CU-512
CU-518 ID-502 MT-504 NE-503
NV-502 NV-503 PR-503 SD-502
US-501 US-512 US-523 US-530
US-595 US-803 US-804 US-805
US-811 US-815 WA-504 WY-501
WY-502 WY-505

221.1a Camping
AK-505 AZ-501 CA-801
CU-514 CU-518 ID-502
MT-504 NE-503 NV-502
NV-503 NV-801 OR-801
PR-503 PR-528 PR-801
PR-802 SD-502 SD-801
US-501 US-512 US-523
US-530 US-561 US-586
US-587 US-595 US-801
US-803 US-804 US-805
US-811 US-815 US-901
WA-504 WA-801 WY-501
WY-502 WY-505

221.1b Picnicking
AZ-501 CA-801 CU-518
ID-502 MT-504 NE-503
NV-502 NV-503 PR-503
SD-502 US-501 US-512
US-523 US-530 US-586
US-587 US-595 US-803
US-804 US-805 US-811
US-815 US-901 WA-504
WY-501 WY-502 WY-505

221.1c Recreation travel (mechanized)
CU-524 ID-502 MT-504
NV-502 PR-503 US-501
US-512 US-595 US-803
US-804 US-811 US-815

221.1d Boating
AZ-501 CU-518 ID-502
MT-504 NE-503 NV-502
NV-503 PR-503 SD-502
US-501 US-512 US-523
US-586 US-587 US-593
US-595 US-636 US-803
US-804 US-811 US-815
US-901 WA-504 WY-501
WY-502 WY-505

221.1e Games and team sports
AZ-501 ID-502 NE-503
NV-502 NV-503 PR-503
US-501 US-512 US-587
US-595 US-803 US-804
US-811 US-815 US-901
WA-504

221.1f Waterskiing and other water sports
AZ-501 CU-518 ID-502
NE-503 NV-502 NV-503
PR-503 SD-502 US-501
US-512 US-523 US-530
US-586 US-593 US-636
US-803 US-804 US-805
US-811 US-815 US-901
WA-504 WY-501 WY-502
WY-505

221.1g Swimming and scuba diving
AZ-501 CA-801 CU-518
ID-502 MT-504 NE-503
NV-502 NV-503 PR-503
SD-502 US-501 US-512
US-523 US-587 US-595
US-636 US-803 US-804
US-811 US-815 US-901
WY-505 WA-504 WY-501
WY-502 WY-505

221.1h Winter sports
AK-505 AZ-501 CU-518
CU-519 CU-523 CU-525
CU-526 CU-527 ID-502
MT-504 NE-503 NV-502
PR-503 PR-529 PR-535
SD-502 US-501 US-512
US-530 US-587 US-595
US-803 US-804 US-805
US-811 US-815 US-901
WA-504 WY-501 WY-505

221.1i Fishing
AK-505 AK-801 AZ-501
CA-801 CU-518 CU-521
CU-522 CU-528 CU-529
HI-801 ID-502 ID-504
MT-504 NE-503 NM-802
NV-502 NV-503 NV-505
OR-504 PR-503 SD-502
SD-801 US-501 US-505
US-512 US-515 US-523
US-530 US-573 US-586
US-587 US-593 US-595
US-605 US-636 US-651
US-803 US-804 US-805
US-811 US-815 US-901
UT-803 WA-504 WA-802
WY-501 WY-502 WY-505
WY-801

221.1j Hunting
AK-505 AK-801 AZ-501
AZ-802 CA-801 CO-802
CU-517 CU-518 CU-528
CU-529 HI-801 ID-502
ID-504 MT-504 MT-802
NE-503 NM-503 NM-802
NV-502 NV-503 NV-505
OR-503 PR-503 SD-502
SD-801 US-501 US-505
US-512 US-515 US-530
US-573 US-574 US-586
US-593 US-595 US-605
US-646 US-803 US-804
US-805 US-811 US-815
UT-803 WA-501 WA-504
WA-802 WY-501 WY-505
WY-801

221.1k Hiking and mountain climbing
AK-505 AZ-501 CA-801
CU-518 ID-502 MT-504
NE-503 NV-502 NV-503
PR-503 SD-502 US-501
US-512 US-587 US-595
US-803 US-804 US-811
US-815 US-901 WA-504
WY-502 WY-505

221.1l Horseback riding
AZ-501 CU-518 ID-502
MT-504 NE-503 NV-502
NV-503 PR-503 SD-502
US-501 US-512 US-595
US-803 US-804 US-811
US-815 WA-504 WY-505

221.1m Resort use
PR-503 US-501 US-512
US-595 US-803 US-804
US-815

221.1n Organization camp use
PR-503 US-501 US-512
US-595 US-803 US-804
US-815

221.1o Recreation residence use
PR-503 US-501 US-512
US-595 US-803 US-804
US-815

221.1p Gathering forest products
PR-503 US-501 US-512
US-595 US-803 US-804
US-815

221.1q Nature study
AZ-501 CA-801 CU-518
ID-502 NV-502 NV-503
PR-503 US-501 US-512
US-595 US-803 US-804
US-815

221.1r Viewing scenes, sports environment
CU-518 PR-503 US-501
US-512 US-595 US-803
US-804 US-815 WY-505

221.1s Visitor information (exhibits, talks, etc.)
PR-503 US-501 US-512
US-595 US-803 US-804
US-815

221.1t Other
AZ-501 CA-801 CU-518
ID-502 MT-504 NE-503
NV-502 NV-503 OR-801
SD-502 US-523 US-530
US-586 US-587 US-805
US-811 US-815 US-901
WA-504 WY-501 WY-502
WY-505

221.2 By type of developed recreation site
PR-503 US-512 US-595 US-803
US-804 US-815

221.2a Observation sites
US-501 US-512 US-595
US-803 US-804 US-815

221.2b Play, park, sports
US-512 US-595 US-803
US-804 US-815

221.2c Boating sites
US-501 US-512 US-593
US-595 US-803 US-804
US-815 WA-504

221.2d Swimming sites
AZ-501 US-501 US-512
US-595 US-803 US-804
US-815 WA-504

221.2e Campgrounds
OR-801 PR-528 PR-801
PR-802 SD-801 US-501

US-512 US-595 US-803
US-804 US-815 WA-504

221.2f Picnic grounds
AZ-501 US-501 US-512
US-595 US-803 US-804
US-815 WA-504

221.2g Hotel, lodge, resorts
PR-528 US-501 US-512
US-595 US-803 US-804
US-815

221.2h Organization sites
US-501 US-512 US-595
US-803 US-804 US-815

221.2i Other concession sites
US-512 US-595 US-803
US-804 US-815

221.2j Recreation residence sites
US-501 US-512 US-595
US-803 US-804 US-815

221.2k Winter sports sites
CU-519 PR-529 PR-535
US-501 US-512 US-595
US-803 US-804 US-815
WA-504

221.2l Document sites
US-512 US-595 US-803
US-804 US-815

221.2m Interpretive sites
US-512 US-595 US-803
US-804 US-815

221.3 By type of dispersed recreation area
PR-503 US-512 US-595 US-803
US-804 US-815

221.3a Roads
US-501 US-512 US-595
US-803 US-804 US-815

221.3b Trails
US-501 US-512 US-595
US-803 US-804 US-815

221.3c Lakes and ponds
US-512 US-595 US-803
US-804 US-815

221.3d Reservoirs
US-512 US-595 US-803
US-804 US-815

221.3e Rivers and streams
US-512 US-595 US-803
US-804 US-815

221.3f Oceans and Great Lakes
US-512 US-595 US-803
US-804 US-815

221.3g General undeveloped area
US-512 US-595 US-803
US-804 US-815

222 Visitor expenditures
AK-505 CU-512 CU-513 CU-514
CU-528 CU-531 OR-501 OR-801
PR-526 PR-528 PR-529 PR-535
SD-801
See also Wildlife and Fish, Participants' expenditures (322)

223 Receipts from recreation activities

223.1 Total revenues from entrance and user fees
AZ-801 CA-503 CU-502 HI-502
MT-505 NE-502 NM-803 NV-801
OR-801 PR-503 PR-528 PR-532
SD-801 US-522 US-575 US-595
US-606 US-805

223.2 Revenues from concessions
AK-802 CA-503 HI-502 MT-505
PR-528 SD-801

224 Specific entrance and user fees
PR-520 PR-521 PR-530 PR-802
US-575 US-672

230 Nonmonetary Data and Impacts

231 Inventories and capacities of recreation facilities and recreation lands
AK-802 AZ-501 CA-503 CU-502
CU-504 CU-511 CU-519 HI-502
ID-502 MT-504 MT-505 NE-502
NE-503 NM-803 NV-502 OR-801
PR-520 PR-521 PR-522 PR-528
PR-530 PR-802 SD-502 US-501
US-530 US-569 US-575 US-586
US-589 US-606 US-657 US-672
US-803 US-804 US-805 WA-504
WY-505

231.1 Inventory of wilderness areas --See Land and Water, Nonmonetary Data and Impacts (630)

231.2 Inventory of other recreation land areas--See Land and Water, Nonmonetary Data and Impacts (630)

;2 Socioeconomic characteristics of visitors or participants

232.1 Age
AK-505 AK-802 CU-518 CU-519
CU-523 CU-525 CU-526 CU-527
CU-528 NV-502 NV-503 OR-501
PR-524 PR-525 PR-529 PR-535
PR-801 PR-901 PR-902 SD-502
US-515 US-574 US-589 US-593
US-657 US-811 US-901 WY-502

232.2 Sex
AK-505 CU-519 CU-525 PR-529
PR-535 US-515 US-587 US-593
US-901 WY-502

232.3 Income
AK-505 CU-512 CU-518 CU-519
CU-523 CU-524 CU-525 CU-526
CU-527 OR-501 PR-524 PR-525
PR-529 PR-535 PR-801 PR-901
PR-902 SD-502 US-515 US-574
US-587 US-593 US-811 US-901

232.4 Other
AK-505 CU-518 CU-519 CU-523
CU-524 CU-525 CU-526 CU-527
CU-528 NV-503 OR-501 PR-524
PR-525 PR-529 PR-535 PR-801
PR-901 PR-902 SD-502 US-574
US-587 US-593 US-811 US-901
See also Wildlife and Fish (630)

;0 Information for Supply and Demand Analyses

;1 Use levels--see Outputs and Their Monetary Values(221)

;2 Inventories and capacities of recreational facilities
AK-802 AZ-501 CA-503 CU-502
CU-504 CU-511 CU-519 HI-502
ID-502 MT-504 MT-505 NE-502
NE-503 NM-803 NV-502 OR-801
PR-520 PR-521 PR-522 PR-528
PR-530 PR-802 SD-502 US-501
US-530 US-569 US-575 US-586
US-589 US-606 US-657 US-672
US-803 US-804 US-805 WA-504
WY-505

243 Origin/destination data
AK-505 AK-802 AZ-501 CU-512
CU-523 CU-525 CU-527 ID-502
NV-503 OR-501 OR-801 PR-524
PR-525 PR-529 PR-901 PR-902
US-574 US-587 US-657 US-811
US-901 WA-504 WY-502

244 Willingness to pay data/Recreation resource values
AK-802 CU-529 US-525

See also Wildlife and Fish (340)

250 Secondary and Indirect Effects

251 Manufacturers of recreation goods

251.1 Units purchased
PR-523

251.2 Consumer expenditures
CU-513 PR-523

See also General Economic and Social Impacts (100)

300 Wildlife and Fish

310 Costs of Management Activities

311 Fish and wildlife planning
US-815

312 Habitat improvement - threatened and endangered animals
US-815

313 Habitat improvement - threatened and endangered plants
US-815

314 Habitat improvement - wildlife
US-815

315 Habitat improvement - fish
US-815

316 Habitat maintenance
US-815

See also Income structure/wage rate (112.3)

320 Outputs and Their Monetary Values

321 Use levels (visitor days and/or number of participants)

321.1 Fishing
AK-505 AK-801 AZ-501 CA-801
CU-518 CU-521 CU-522 CU-528
CU-529 HI-801 ID-502 ID-504
MT-504 NE-503 NM-802 NV-502
NV-503 NV-505 OR-504 PR-503
SD-502 SD-801 US-501 US-505
US-512 US-515 US-523 US-530
US-573 US-586 US-587 US-593
US-595 US-605 US-636 US-651
US-803 US-804 US-805 US-811
US-901 UT-803 WA-504 WA-802
WY-501 WY-502 WY-505 WY-801

321.2 Wildlife observation
OR-503 US-515

321.3 Clamming, crabbing and shell collection
US-515 WA-504

321.4 Hunting
AK-505 AK-801 AZ-501 AZ-802
CA-801 CO-802 CU-517 CU-518
CU-528 CU-529 HI-801 ID-502
ID-504 MT-504 MT-802 NE-503
NM-503 NM-802 NV-502 NV-503
NV-505 OR-503 PR-503 SD-502
SD-801 US-501 US-505 US-512
US-515 US-530 US-573 US-574
US-586 US-593 US-595 US-605
US-646 US-803 US-804 US-805
US-811 UT-803 WA-501 WA-504
WA-802 WY-501 WY-505 WY-801

321.5 Recreational shooting
US-515

321.6 Wildlife photography
OR-503 US-515

321.7 Archery
MT-504 US-515 WY-801

322 Participants' expenditures

322.1 Food, drink and refreshments
CO-802 CU-528 SD-801 US-515
UT-803 WY-801

322.2 Lodging
CO-802 CU-528 SD-801 US-515
UT-803 WY-801

322.3 Transportation
CO-802 CU-528 SD-801 US-515
UT-803 WY-801

322.4 Fishing equipment
CO-802 PR-523 SD-801 US-515
UT-803 WY-801

322.5 Hunting equipment
CO-802 PR-523 SD-801 US-515
UT-803 WY-801

322.6 Fees, licenses, tags and stamps
AK-801 AZ-802 CA-501 CA-801
CO-802 CU-502 CU-504 CU-506
CU-528 CU-531 HI-502 HI-801
ID-504 MT-505 MT-802 NE-502
NM-503 NM-802 NV-505 OR-503
OR-504 PR-503 SD-801 US-501
US-515 US-516 US-518 US-576
UT-803 WA-802 WY-501 WY-801
See also Recreation and Wilderness System (220)

323 Commercial fish production
AK-507 AK-801 HI-502 OR-504
US-501 US-589 US-606 US-651
US-652 US-802 UT 803 WA-501

324 Commercial fish value
AK-507 AK-801 HI-502 US-589
US-651 US-652

330 Nonmonetary Data and Impacts

331 Socioeconomic characteristics of participants

331.1 Age
CU-522 CU-528 SD-801 US-515
US-574 UT-803 WY-801

331.2 Sex
CU-522 SD-801 US-515 UT-803

331.3 Income
SD-801 US-515 US-574 UT-803
WY-801

331.4 Other
CU-528 SD-801 US-574 UT-803
WY-801

2 Inventories and/or population
stimates

332.1 Fish
AK-801 CO-802 HI-801 ID-504
NM-503 NM-802 OR-504

332.2 Wildlife and game and waterfowl
AK-801 AZ-802 CO-802 HI-801
ID-504 NE-502 NM-802 NV-505
OR-503 US-530 US-573 US-577
US-605 US-646 US-802 US-805
UT-803 WA-501 WA-802

3 Hunter harvest
AK-801 AZ-802 CA-801 CO-802
CU-517 HI-801 ID-504 MT-504
MT-802 NE-502 NM-503 NM-802
NV-502 NV-505 OR-503 PR-503
SD-801 US-515 US-573 US-586
US-605 US-646 US-647 US-802
UT-803 WA-501 WA-802 WY-501
WY-505 WY-801

4 Sport fish caught
AK-801 CU-521 HI-801 ID-504
NM-802 NV-505 OR-504 SD-801
US-586 US-651 US-802 UT-803
WA-509 WA-802

5 Number of licenses and stamps sold
AK-801 AZ-802 CA-801 CO-802
CU-528 CU-531 HI-502 HI-801
ID-504 MT-504 MT-802 NE-502
NE-503 NM-503 NM-802 NV-502
OR-503 OR-504 SD-801 US-574
US-576 US-606 US-646 UT-803
WA-802 WY-801

0 Information for Supply and Demand Analyses

1 Use levels (visitor days and/or
mber of participants)--see Outputs and
eir Monetary Values (321)

2 Participants' expenditures--see
tputs and their Monetary Values (322)

3 Number of fishing waters
CU-529 ID-502 MT-504 NM-503
NV-502 US-802 WY-505

4 Number of hunting grounds
CU-517 CU-529 US-802

345 Inventories and hunter harvest--see Nonmonetary Data and Impacts (332, 334, 335)

350 Secondary and Indirect Effects

351 Hunting and fishing supplies

351.1 Units purchased
PR-523

351.2 Consumer expenditures
CO-502 PR-523 SD-801 US-515
UT-803 WY-801

400 Range

410 Costs of Management Activities

411 Range resource planning and inventory
US-815

412 Range resource management
US-815

413 Range forage improvement
US-815

414 Range forage improvement maintenance
US-815

415 Range structural improvements
US-815

416 Maintenance of range structural improvements
US-815

417 Wild horse and burro management
US-815

See also Income structure/wage rate 112.3

420 Outputs and Their Monetary Values

421 Grazing in the national forest system

421.1 Number of animals grazing
US-501 US-505 US-512 US-514
US-595 US-605 US-606 US-812

421.2 Animal months
US-512 US-514 US-595 US-812

421.3 Animal unit months
US-512 US-514 US-595 US-660
US-812 US-815

421.4 Grazing receipts
US-505 US-595 US-605 US-812

422 Grazing on other public lands.

422.1 Number of animals grazing
US-530 US-672 US-805 US-813

422.2 Animal months
US-530 US-805 US-813

422.3 Animal unit months
US-530 US-606 US-660 US-672
US-805 US-813

422.4 Grazing receipts
AZ-503 CO-503 ID-501 MT-507
US-530 US-606 US-805 US-813
WY-506

423 Livestock production
AK-507 CA-501 CA-504 CO-501
CU-502 CU-515 ID-503 MT-501
MT-503 NE-501 NE-504 NM-501
NV-504 PR-501 PR-503 PR-533
US-529 US-550 US-552 US-563
US-566 US-567 US-568 US-606
US-638 US-639 US-658 UT-501
WA-508 WY-501 WY-503

424 Livestock prices and/or price indexes
AK-507 CA-501 CA-504 CO-501
CU-501 CU-502 CU-515 ID-503
MT-501 MT-503 NE-501 NE-504
NM-501 NV-504 PR-501 PR-503
PR-533 US-529 US-546 US-547
US-550 US-552 US-558 US-563
US-566 US-567 US-568 US-570
US-571 US-572 US-606 US-638
US-639 US-658 UT-501 WA-508
WY-501 WY-503

425 Forage production
US-660 US-815

430 Nonmonetary Data and Impacts

431 Livestock inventories
CA-501 CA-504 CO-501 CU-515
ID-503 MT-501 MT-503 NE-504
NM-501 NV-504 PR-501 PR-533
US-530 US-566 US-567 US-606
US-638 US-639 US-658 US-805
US-813 UT-501 WA-508 WY-501
WY-503

432 Inventories of grazing areas
US-530 US-550 US-552 US-656
US-660 US-805 US-813

433 Range Productivity
US-660

440 Information for Supply and Demand Analyses

441 Livestock production
AK-507 CA-501 CA-504 CU-501
CU-502 CU-515 ID-503 MT-501
MT-503 NE-501 NE-504 NM-501
NV-504 PR-501 PR-503 PR-533
US-529 US-550 US-552 US-563
US-566 US-567 US-568 US-606
US-638 US-639 US-658 UT-501
WA-508 WY-501 WY-503

442 Livestock inventories
CA-501 CA-504 CO-501 CU-515
ID-503 MT-501 MT-503 NE-504
NM-501 NV-504 PR-501 PR-533
US-530 US-566 US-567 US-606
US-638 US-639 US-658 US-805
US-813 UT-501 WA-508 WY-501
WY-503

443 Capacity of grazing lands
US-656 US-815

444 Consumption of livestock products
CO-501 NE-504 PR-533 US-563
US-567

445 Livestock prices and/or price indexes
AK-507 CA-501 CA-504 CO-501
CU-501 CU-502 CU-515 ID-503
MT-501 MT-503 NE-501 NE-504
NM-501 NV-504 PR-501 PR-503
PR-533 US-529 US-546 US-547
US-550 US-552 US-558 US-563
US-566 US-567 US-568 US-570
US-571 US-572 US-606 US-638
US-639 US-658 UT-501 WA-508
WY-501 WY-503

446 Demand and supply projections
US-550 US-552 US-660

450 Secondary and Indirect Effects

Trade of livestock products

451.1 Amount of imports
PR-533 US-507 US-552 US-558
US-566 US-567

451.2 Value of imports
US-507 US-566

451.3 Amount of exports
PR-533 US-508 US-552 US-558
US-566 US-567

451.4 Value of exports
US-508 US-566

451.5 Trade within the United States; regional trade
CA-504 NM-501

0 Timber

1 Costs of Management Activities

1 Timber resource management planning r inventories
US-815

1 Silvicultural examination and rscription
US-815

1 Reforestation
US-505 US-815 WA-507

1 Timber stand improvement
US-505 US-815 WA-507 WA-803

1 Timber sale preparation
US-815 WA-803

1 Timber harvest administration
US-671 US-815 WA-507

1 Nursery management
US-815

1 Nursery expansion or improvement
US-815

1 Resource interaction ues/opportunity costs
CU-516 WA-507

e also Income structure/wage rate 12.3)

520 Outputs and Their Monetary Values

521 Timber

521.1 Output--removals, cut, harvest, lumber production
AK-501 AK-502 AK-507 AZ-503
CA-501 CA-505 CA-802 CO-801
CU-501 CU-503 CU-505 CU-506
CU-508 CU-516 CU-520 CU-531
CU-532 HI-501 HI-502 ID-501
ID-802 MT-501 MT-801 NM-801
OR-502 PR-502 PR-503 PR-505
PR-506 PR-507 PR-509 PR-510
PR-511 PR-512 PR-513 PR-514
PR-515 PR-527 PR-533 US-501
US-503 US-504 US-505 US-506
US-511 US-512 US-524 US-526
US-528 US-529 US-530 US-532
US-533 US-534 US-535 US-536
US-538 US-539 US-541 US-544
US-550 US-552 US-556 US-579
US-589 US-591 US-595 US-596
US-599 US-600 US-601 US-602
US-603 US-605 US-606 US-637
US-642 US-643 US-644 US-653
US-672 US-805 US-815 UT-801
WA-501 WA-502 WA-503 WA-505
WA-510 WA-803 WY-506

521.2 Timber value and prices, stumpage prices and lumber prices
AK-502 AK-507 AZ-503 CA-505
CA-802 CO-801 CU-516 CU-531
ID-501 ID-802 MT-801 NM-801
PR-503 PR-505 PR-506 PR-507
PR-509 PR-510 PR-511 PR-512
PR-515 PR-527 PR-533 US-501
US-503 US-504 US-505 US-506
US-511 US-512 US-528 US-529
US-530 US-532 US-535 US-538
US-539 US-540 US-542 US-571
US-572 US-595 US-605 US-606
US-654 US-672 US-805 WA-501
WA-507 WA-803 WY-506

522 Pulp and paper products

522.1 Production
CU-531 CU-532 PR-518 PR-519
PR-533 PR-534 US-504 US-529
US-532 US-644 WA-505

522.2 Pulp and paper prices
CU-531 PR-519 PR-533 US-504
US-529 US-532 US-571 US-572
US-654

523 Wholesale price indexes for timber products
PR-514 PR-517 PR-519 PR-534
US-501 US-504 US-505 US-506
US-524 US-529 US-532 US-546
US-547 US-570 US-571 US-572
US-605 US-606 US-616 US-633

524 Revenues from timber products

524.1 U.S. Forest Service revenues
US-511 US-512 US-528 US-595
US-605 US-606 US-633

524.2 Other public agency revenues
AK-502 AZ-503 CA-505 CA-802
CO-503 CO-801 CU-502 HI-502
ID-501 ID-802 MT-507 MT-801
NM-801 OR-502 SD-501 US-530
US-606 US-672 US-805 UT-801
WA-803 WY-506

530 Nonmonetary Data and Impacts

531 Timber inventories

531.1 Net volume
CO-502 CU-501 CU-508 CU-510
CU-520 CU-531 HI-501 ID-802
MT-501 NM-502 NM-801 PR-527
US-501 US-503 US-505 US-506
US-533 US-534 US-535 US-536
US-537 US-541 US-544 US-555
US-556 US-579 US-596 US-624
US-625 US-626 US-627 US-633
US-637 US-640 US-642 US-643
US-653 WA-506

531.2 Area of commercial timber lands
CA-501 CO-502 CU-501 CU-503
CU-508 CU-510 CU-520 CU-531
MT-501 NM-502 NM-801 PR-527
US-501 US-505 US-506 US-530
US-533 US-534 US-535 US-536
US-537 US-541 US-544 US-550
US-555 US-556 US-579 US-589
US-596 US-624 US-625 US-626
US-627 US-633 US-637 US-640
US-642 US-643 US-653 US-805
WA-506 WA-507

531.2a Public
CA-501 CO-502 CU-501
CU-508 CU-520 CU-531
MT-501 NM-502 NM-801
PR-527 US-501 US-505
US-506 US-530 US-534
US-535 US-536 US-541
US-544 US-555 US-556
US-589 US-596 US-625
US-627 US-633 US-637
US-640 US-643 US-653
US-805 WA-506 WA-507

531.2b Private
CA-501 CU-501 CU-508
CU-520 CU-531 MT-501
NM-502 NM-801 PR-527
US-501 US-505 US-506
US-534 US-535 US-536
US-541 US-544 US-555
US-556 US-589 US-596
US-625 US-627 US-633
US-637 US-640 US-642
US-643 US-653 WA-506
WA-507

531.3 Change in net volume

531.3a Annual growth
CO-502 CU-501 CU-508
CU-520 CU-531 US-501
US-505 US-506 US-533
US-534 US-535 US-536
US-537 US-541 US-544
US-556 US-579 US-596
US-624 US-625 US-627
US-637 US-640 US-643
US-653

531.3b Allowable cut or harvest
CU-520 CU-531 ID-802
MT-801 US-503 US-512
US-530 US-533 US-805

532 Consumption of timber products

532.1 Total
US-633

532.2 Per capita
US-501 US-504 US-605 US-60

533 Labor productivity in timber products industry
CU-507 PR-533 US-535 US-659

540 Information for Supply and Demand Analyses

541 Timber output, value and prices--see Outputs and Their Monetary Values (521)

:2 Timber inventories--see Nonmonetary :ta and Impacts (531)

:3 Demand for and consumption of timber :oducts
PR-514 PR-519 PR-533 US-504
US-505 US-506 US-532 US-536
US-591 US-633 US-644 WA-503
WA-505

:4 Demand and supply projections
CA-802 CU-508 CU-520 US-506
US-535 US-536 US-542 US-550
US-552 US-556 US-633 US-642
WA-506 WA-507

Secondary and Indirect Effects

:1 Manufacturing

551.1 Wood products consumed
CU-532 PR-519 PR-534 US-504
US-506 US-510 US-591 US-599
US-600 US-601 US-602 US-603
US-644 WA-505

551.2 Receipts of manufacturers
AK-507 CU-502 CU-532 CU-533
US-633

551.3 Value of shipments and/or inventories
CU-532 PR-503 US-532 US-633
US-644

551.4 Value added
CU-504 CU-507 CU-531 CU-533
MT-501

.2 Construction industry

552.1 Wood products consumed
US-504 US-509 US-524

552.2 Value of new construction
AK-507 CU-502 MT-501 PR-501
PR-503 PR-514 US-501 US-524
US-529 US-606

552.3 Receipts of construction establishments
AK-507 CU-502 PR-503 US-501

552.4 Value added
PR-503 US-606
see also Housing (140)

553 Trade in timber products

553.1 Amounts of imports
PR-512 PR-514 PR-519 PR-527
PR-533 PR-534 US-501 US-503
US-504 US-505 US-506 US-507
US-532 US-605 US-606 US-633
US-644 WA-503

553.2 Value of imports
PR-512 PR-533 PR-534 US-501
US-503 US-506 US-507 US-532
US-606

553.3 Amount of exports
AK-507 PR-505 PR-508 PR-512
PR-513 PR-514 PR-515 PR-519
PR-527 PR-534 US-501 US-503
US-504 US-505 US-506 US-508
US-532 US-605 US-606 US-644
WA-503 WA-505

553.4 Value of exports
AK-507 PR-512 PR-534 US-501
US-503 US-506 US-508 US-532

553.5 Amount and/or value of United States regional trade
PR-513 PR-515 PR-527 US-591
WA-505

553.6 World forest resources and inventories
PR-508 US-506

553.7 World production and consumption of forest products
PR-508 PR-512 US-506

554 Cooperative forest management programs
US-501 US-512 US-595

554.1 Subsidy amounts or expenditures
US-505 US-512

554.2 Woodland owners assisted
US-501 US-505 US-512 US-595

554.3 Area of woodland involved
US-501 US-505 US-512 US-595

554.4 Products harvested
US-501 US-505

554.5 Gross sale value
US-501 US-505

600 Land and Water

610 Costs of Management Activities

611 Land exchange
US-815

612 Land acquisition
US-815

613 Soil resource

613.1 Soil resource inventory
US-815

613.2 Soil monitoring
US-815

613.3 Soil resource improvement
US-625 US-815

613.4 Soil resource improvement maintenance
US-635 US-815

614 Road and bridge construction and maintenance
US-634 US-815 WA-803

615 Trails

615.1 Trail construction

615.2 Trail system management
US-815

616 Fire and fuel planning and management

616.1 Fire prevention
US-506 US-512 US-530 US-805
US-815

616.2 Fire detection
US-815

616.3 Fuel management inventory
US-815

616.4 Treatment of activity fuels
US-815

616.5 Treatment of natural fuels
US-815

616.6 Fuelbreak construction
US-815

616.7 Fuel treatment area maintenan
US-815

616.8 Vegetation treated by burninc
US-635 US-815

616.9 Fire suppression
US-506 US-512 US-530 US-80
US-815

617 Insect and disease management
US-815

618 Water resource planning and management

618.1 Water resource inventory
US-815

618.2 Water resource monitoring
US-815

618.3 Water resource improvement
US-635 US-656 US-815

618.4 Water resource improvement maintenance
US-815

See also Income structure/wage rate (112.3)

620 Outputs and Their Monetary Values

621 Water yield/water supply
CA-507 PR-501 US-501 US-531
US-588 US-590 US-607 US-608
US-609 US-610 US-611 US-612
US-613 US-620 US-636 US-809
US-810 US-815 WY-501

622 Water uses

622.1 Agriculture/irrigation
HI-501 PR-501 US-501 US-58
US-606 US-636 WY-501

622.2 Domestic

622.2a Total
PR-501 US-588 US-636

622.2b Per capita
HI-501 US-501

622.3 Mining
PR-501 US-588 US-614 US-636

622.4 Other
PR-501 US-588 US-606 US-636
WY-501

63 Public revenues from land rentals
ad leases
CO-503 HI-502 MT-507 US-672
WY-506

3 Nonmonetary Data and Impacts

51 Land areas of the national forest
stem
US-513 US-530 US-660

631.1 Areas by region
US-513

631.2 Areas by states
MT-501 PR-503 US-512 US-513
US-660

631.3 Area by Congressional
districts and/or counties
MT-501 US-513

631.4 National Game Refuges
US-513

631.5 National Wilderness and
Primitive Areas
CU-506 CU-531 US-513 US-595
US-636

631.6 National Recreation Areas
US-513

631.7 National Wild and Scenic
Rivers
US-513

631.8 National Scenic--Research Area
US-513

2 Land ownership

632.1 Public lands

632.1a Amount
AZ-503 CU-502 CU-503
CU-505 HI-501 HI-502
MT-501 MT-507 PR-501
PR-503 SD-501 US-501
US-530 US-535 US-543
US-579 US-589 US-606
US-643 US-653 US-670
US-672 WY-501 WY-505

632.1b Activities
CU-506 MT-501 MT-507
PR-503 SD-501 US-501
US-530 US-535 US-543
US-589 US-606 US-670

632.2 Private lands

632.2a Amounts
AZ-503 CU-502 CU-503
CU-505 HI-501 HI-502
MT-501 PR-501 PR-503
SD-501 US-501 US-535
US-579 US-589 US-606
US-643 US-653 US-670
WY-501 WY-505

632.2b Activities
MT-501 SD-501 US-535
US-589 US-606 US-670

See also Timber, Nonmonetary Data and
Impacts, Timber Inventories (531)

633 Inventories of types of land

633.1 Rangeland
US-530 US-550 US-552 US-637
US-660 US-670 US-805

633.2 Forest land
CU-531 OR-502 US-605 US-606
US-636 US-637 US-640 US-643
US-653 US-660 US-670

633.2a Commercial forest land--
see Timber inventories (531.2)

633.2b Noncommercial forest
land
CO-502 CU-531 US-533
US-534 US-535 US-537
US-541 US-544 US-555
US-579 US-589 US-596
US-624 US-625 US-626
US-627 US-637 US-640
US-643 US-653

633.3 Wilderness
CU-531 US-636 US-643 WA-504

633.4 Others
CU-531 US-533 US-534 US-535
US-537 US-541 US-544 US-550
US-552 US-555 US-579 US-596
US-624 US-625 US-626 US-627
US-632 US-636 US-637 US-640
US-643 US-653 US-660 US-670

634 Water yield/water supply
CA-507 PR-501 US-501 US-531
US-588 US-590 US-607 US-608
US-609 US-610 US-611 US-612
US-613 US-620 US-636 US-809
US-810 US-815 WY-501

634.1 Precipitation data
US-607 US-609 US-611 US-613
US-814

634.2 Snow measurements
US-607 US-610 US-613 US-814

634.3 Water discharge
CA-507 US-531 US-588 US-590
US-607 US-609 US-611 US-612
US-613 US-620 US-636 US-809
US-810

640 Information for Supply and Demand Analyses

641 Water yield/water supply
CA-507 PR-501 US-501 US-531
US-588 US-590 US-607 US-608
US-609 US-610 US-611 US-612
US-613 US-620 US-636 US-809
US-810 US-815 WY-501

642 Water uses

642.1 Agriculture/irrigation
HI-501 PR-501 US-501 US-588
US-606 US-636 WY-501

642.2 Domestic
PR-501 US-588 US-636

642.3 Mining
PR-501 US-588 US-614 US-636

642.4 Others
PR-501 US-588 US-606 US-636
WY-501

643 Land values

643.1 Assessed valuation by county
AK-507 CU-502 MT-501 MT-502
PR-503 SD-501

643.2 Land values of timber lands
CU-516 WA-507 WY-501

643.3 Land values of range lands, open land and other holdings.
AK-507 WY-501

650 Secondary and Indirect Effects

651 Water quality data

651.1 Water contents
CA-507 PR-503 US-531 US-620
US-809 US-810

651.2 Sediment discharge
CA-507 US-531 US-620 US-636
US-809 US-810

700 Minerals and Energy

710 Costs of Management Activities

711 Minerals management
US-815

712 Mined area reclamation
US-815

713 Mineral character or potential evaluations
US-815

714 Geological planning and inventory
US-815

715 Mine investment costs
US-661 US-662 US-663 US-664
US-665 US-666 US-667

716 Mine operating costs
US-661 US-662 US-663 US-664
US-665 US-666 US-667

717 Reclamation costs
US-673

See also income structure/wage rate (112.3)

720 Outputs and Their Monetary Values

2 Mineral production

AK-507 CA-501 CU-501 CU-502
CU-505 CU-506 HI-501 MT-501
MT-508 NE-501 PR-501 PR-503
PR-533 SD-501 US-501 US-529
US-530 US-564 US-565 US-580
US-581 US-582 US-583 US-584
US-585 US-589 US-597 US-598
US-606 US-614 US-617 US-618
US-805 US-806 US-815 US-907
WY-501 WY-504

2 Mineral value and prices and/or
ce indexes

AK-507 CA-501 CU-501 CU-502
CU-503 CU-504 CU-505 CU-506
HI-501 MT-501 NE-501 PR-501
PR-533 US-501 US-547 US-564
US-565 US-580 US-581 US-582
US-583 US-584 US-589 US-597
US-606 US-614 US-616 US-618
US-805 US-907 WY-501 WY-504

2 Energy production

AK-507 CA-501 MT-506 PR-503
PR-533 PR-536 US-629 US-631
US-501 US-645 US-648

2 Energy prices

MT-506 PR-531 PR-533 US-501
US-629 US-631 US-645

2 Federal and other government revenue

725.1 Royalty income

AZ-503 CO-503 ID-501 MT-507
US-564 US-565 US-595 US-606
US-618 US-672 WY-504 WY-506

725.2 Bonus received

PR-503 US-503

3 Nonmonetary Data and Impacts

Known mineral reserves

US-580 US-581 US-806

Labor productivity in the mineral
ustry

PR-533 US-580 US-659

Mineral leases and permits

AZ-503 PR-503 MT-506 MT-507
US-530 US-564 US-565 US-595
US-614 US-618 US-672 US-805
US-815 US-907 WY-506

740 Information for Supply and Demand Analyses

741 Mineral and energy reserves and production

741.1 United States mineral and energy reserves

MT-506 PR-503 US-580 US-581
US-583 US-806

741.2 United States mineral production--see Outputs and Their Monetary Values (721)

741.3 World mineral reserves

US-581 US-583 US-806

741.4 World mineral production

US-580 US-581 US-582 US-583
US-584 US-597 US-598 US-806

742 Consumption

742.1 U.S. mineral consumption

PR-533 US-580 US-581 US-582
US-583 US-584 US-585 US-597
US-606 US-617 US-619

742.2 World mineral consumption

US-619

742.3 Per capita mineral use

US-619

742.4 Energy and energy products consumption

CA-501 HI-501 MT-506 MT-508
NE-501 PR-501 PR-502 PR-503
PR-531 PR-533 PR-536 SD-501
US-501 US-617 US-629 US-631
US-636 US-645 US-648 US-649

742.5 Per capita energy use

PR-531 PR-536 SD-501 US-501
US-645

743 Demand and supply projections

US-501 US-619 US-629 US-631
US-645 US-648

750 Secondary and Indirect Effects

751 Manufacturing

751.1 Mineral and energy products consumed

MT-508 US-582 US-583 US-585
US-597 US-614 US-649 US-907

751.2 Receipts of manufacturers
AK-507 CU-502 US-614 US-907

751.3 Value added
CA-501 CU-505 CU-506 US-501
US-606 US-614 US-907

752 Trade in mineral and energy products

752.1 Amount of imports
MT-506 PR-533 PR-536 US-501
US-507 US-580 US-581 US-582
US-583 US-584 US-585 US-597
US-598 US-606 US-616 US-629
US-631 US-645 US-648

752.2 Value of imports
MT-506 US-501 US-507 US-580
US-597 US-598 US-631 US-648

752.3 Amount of exports
PR-533 PR-536 US-501 US-508
US-580 US-581 US-582 US-583
US-584 US-597 US-598 US-606
US-616

752.4 Value of exports
US-501 US-508 US-580 US-597
US-598

752.5 Amount and/or value of United States regional trade
MT-506 US-580

DATA SOURCES AND DESCRIPTIONS

Alaska State Government

AK-501

Alaska Statistical Review. State of Alaska, Department of Economic Development, Division of Economic Enterprise, Pouch EE, Juneau, AK 99801

A periodical statistical guide to the economy of Alaska, last issued as of this writing in 1972, with supplements added in more recent years. A section also covers "Alaska's people--including demographic, employment, education, and income information." There is also a small general section on Alaska's state government.

AK-502

Monthly Cut and Sold Report. State of Alaska, Department of Natural Resources Division of Land and Water Management, 323 E. 4th Ave., Anchorage, AK 99501

These reports review the volume and value of timber cut and sold on Alaska state lands.

AK-503

Alaska Economic Trends. State of Alaska Department of Labor, Research and Analysis Section, P.O. Box 1149, Juneau, AK 99811

This monthly publication reviews employment and other related economic data for the State of Alaska.

AK-504

Statistical Quarterly. Alaska Department of Labor, Research and Analysis Section, P.O. Box 3-7000, Juneau, AK 99811

This publication, issued quarterly, is a compilation of covered employment and payroll data by industry and geographic divisions. Classification of data by industry is by Standard Industrial Classification.

AK-505

Visitor Census and Expenditure Survey. 1978. State of Alaska, Department of Commerce and Economic Development, Division of Economic Enterprise, Pouch EE, Juneau, AK 99801

Data profiling visitors to Alaska and measuring their expenditures are presented in this series of reports. The survey was taken during the winter 1976-1977, and the individual months of June, July, August and September, 1977 A related report, Visitor Related Firm Survey for the Year 1975, details the direct impact of visitor spending on Alaska's businesses and on the State's economy.

AK-506

T?e Alaska Economic Information and Re-
p:ting System. State of Alaska, Department of Commerce and Economic Development, Division of Economic Enterprise, Pouch EE, Juneau, AK 99801

This quarterly report contains historical and projected statistics of several economic indicators for the State o Alaska.

AK-507

T?e Alaska Economy: Year-End Performance Report. State of Alaska, Department of Commerce and Economic Development, Division of Economic Enterprise, Pouch EE, Juneau, AK 99801

"This (annual) report presents an examination of the trends in Alaska's economy during the year that has just passed, and also reviews the performance of the State's economy during the last few years. The first part of this report is a description of Alaska's economic sectors grouped by such subjects a the mineral industry, petroleum and natural gas, fisheries, and forest products, and is accompanied by charts and photographs. The second and final part i a statistical documentation of the first part. Sources for the data contained in the statistical section have been credited on each tabulation."

AK-801

Alaska Department of Fish and Game, Support Bldg., Juneau, AK 99801

The Alaska Department of Fish and Game collects numerous types of data that are available on request. Various reports have harvest information, data o license sales and revenues, number of hunting and fishing days, and population estimates.

AK-802

State of Alaska, Department of Natural Resources, Division of Parks, 619 Warehouse Dr., Suite 210, Anchorage, AK 9501

The Division of Parks collects pertinent data that is available on request. This includes visitor counts conducted in state parks on a continuing basis and the results of a visitor survey conducted in 1977. At this writing a demand survey was also being conducted.

Arizona State Government

AZ-501

Arizona Statewide Comprehensive Outdoor Recreation Plan. Arizona Outdoor Recreation Coordinating Commission, 4433 N. 19th Ave., Suite 203, Phoenix, AZ 85015

Outdoor recreation plan for Arizona, updated approximately every fifth year, containing an evaluation of the demand for and supply of outdoor recreation resources and facilities in Arizona and a program for the implementation of the plan. The total plan consists of a narrative text, and a separate technical document providing demand and supply data. This plan is required by the Land and Water Conservation Fund Act of 1965 (Public Law 88-578). At this writing, the last revision of the plan was issued in 1978.

AZ-502

Arizona Labor Market Newsletter. Department of Economic Security, Manpower Information and Analysis, P.O. Box 6123, Phoenix, AZ 85005

This monthly report presents summary employment data for Arizona. Additional information is available on request.

AZ-503

Arizona State Land Department: Annual Report. Arizona State Land Department, 1624 W. Adams, Phoenix, AZ 85007

This annual report summarizes the Land Department's duties in water, forestry, soil conservation, and trust land management. Pertinent data are presented.

AZ-801

Arizona State Parks Board, 1688 W. Adams St., Phoenix, AZ 85007

Unpublished data, available on request, dealing with attendance in state parks and revenue from state parks.

AZ-802

Arizona Game and Fish Department, 2222 W. Greenway Rd., Phoenix, AZ 85023

The Arizona Game and Fish Department collects numerous types of data that are available on request, including harvest information, license sales and revenues, and number of hunting days. Some of the information is included in performance reports.

California State Government

CA-501

California Statistical Abstract. State of California, Documents Section, P.O. Box 20191, Sacramento, CA 95820

A periodical (generally yearly) publication, edited by the California Department of Finance, Financial Research Section, containing data on social, political, economic and physical aspects of California. Data sources are given, as well as a list of source contributors and their addresses.

CA-502

California Economic Indicators. State of California, Department of Finance, P.O. Box 151, Sacramento, CA 95814

"California Economic Indicators is a bimonthly summary of economic data relating to California. In addition to basic statistical compilations, charts showing monthly and quarterly series are included to facilitate review of current developments and appraisal of their significance on the state's economy." Data includes employment, income and price indexes. "Sources are cited from which further detail on the various statistical series published can be obtained."

CA-503

Statistical Report. State of California--The Resources Agency, Department [of] Parks and Recreation, P.O. Box 2390, Sacramento, CA 95811

Annual report providing informatio[n] about recreation facilities and units owned by the Department of Parks and Recreation. Data categories include t[he] number of camping and picnic units, operating costs, revenues from fees a[nd] concessions, and visitor attendance. There are also summary statistics for counties and other areas.

CA-504

California Livestock Statistics. Stat[e] of California, Department of Food and Agriculture, California Crop and Livestock Reporting Service, P.O. Box 125[?] Sacramento, CA 95806

Annual "compilation of official estimates of livestock inventory numbers, production, income and related statistical information."

CA-505

California State Forests. California Department of Forestry, 1416 Ninth St., Sacramento, CA 95814

This annual report summarizes activities of the past year in California's state forests. General information o[n] recreation use, timber harvest and timber sale revenue is included in this report. More detailed information is available on request.

CA-506

California Employment and Payrolls. California Employment Development Department, 800 Capitol Mall, Sacramento, C[A] 95814

This publication, issued quarterly, is a compilation of covered employment and payroll data by industry and geographic divisions. Classification of

ta by industry is by Standard dustrial Classification.

CA-507

dex to Sources of Hydrologic Data. lifornia Department of Water Resources, P.O. Box 388, Sacramento, CA 302

is publication, issued about every two ars as Bulletin 230, summarizes information in California for sources of hydologic data. The first edition, issued 1978, "comprises four independent sections: an index to surface water measement stations, an index to surface ter quality stations, an inventory of ound water wells and data, and a list current publications on climatological data." The Department of Water sources' Water Data Information Sysn, "a computer-based system that esently manages water quality data, ound water level measurements, and ound water quality data" is also scribed.

CA-801

lifornia Department of Fish and Game, sources Bldg., 1416 Ninth St., Sacranto, CA 95814

The California Department of Fish d Game collects various types of usel data on an annual basis. Much of information is in the following inrnal reports, available upon request:

1) "Report of the (Year) Game Take nter Survey"

2) "Public Recreation Use on Stateed or Operated Areas" Unpublished a on hunting and fishing licenses are so available upon request.

CA-802

lifornia Department of Forestry, 1416 th St., Sacramento, CA 95814

The California Department of Forry collects various types of useful a relevant to California State Fors and other forestry and timber topics for California. Of particular note is California State Forests (see CA-505) and the State Forest Notes series. This series, which covers a wide range of subjects, regularly contains data on production of California timber operators. Also worth mentioning is State Forest Note No. 71, Timber Projections for California, Production vs. Consumption, issued in 1978. Further information is available on request. Please note that prior to January, 1977, this agency was the California Division of Forestry.

Colorado State Government

CO-501

Colorado Agricultural Statistics. Colorado Department of Agriculture, State Services Building, 1525 Sherman Street, Denver, CO 80203

(In cooperation with the U.S. Department of Agriculture, Colorado Crop and Livestock Reporting Service)

Annual compilation of crop and livestock production statistics, and income and price data for the state of Colorado.

CO-502

Private and State Timber Resources. 1974. Colorado State Forest Service, Colorado State University, Ft. Collins, CO 80523

(The Colorado State Forest Service is a division of Colorado State University and is a section of the Division of Natural Resources, State of Colorado.)

"This publication is the summary for the series of twenty inventory releases presenting inventory data for private and state-owned timberlands in Colorado. The county-by-county inventory of private and state forest land has been published in twenty Timber Resource Inventory Releases as the work was completed." At this writing, a timber inventory of state lands is being taken, with results expected to be published in 1979.

CO-503

Summary of Transactions of State Board of Land Commissioners of Colorado. State Board of Land Commissioners, 1313 Sherman St., Denver, CO 80203.

This annual report presents data on the affairs of the Board of Land Commissioners, including revenues and acreage leased by activity.

CO-801

Colorado State Forest Service, Colorado State University, Ft. Collins, CO 80523

(The Colorado State Forest Service is a division of Colorado State University and is a section of the Division of Natural Resources, State of Colorado.)

Unpublished timber sales data on state lands available upon request. Some timber harvest data on privately owned lands is also available.

CO-802

Colorado Department of Natural Resources, Division of Wildlife, 6060 Broadway, Denver, CO 80216

The Colorado Division of Wildlife collects numerous types of data that are available on request, including harvest information, license sales and revenues, and number of hunting days. Much of the data is included in Federal aid completion reports. In addition the Department of Economics, Colorado State University, as part of a cooperative research agreement with the Division of Wildlife, issued a publication in 1975 called A Survey of Sportsmen Expenditures for Hunting and Fishing in Colorado, 1973.

CO-803

Colorado Division of Employment and Training, 251 E. 12th Ave., Denver, CO 80203

The Division of Employment and Training collects several types of data that are available on request including number of employees and payroll data by industry. Much of the information is included in various reports including the monthly Colorado Manpower Review and manpower summaries issued for several areas on a monthly or quarterly basis.

Colleges and Universities

CU-501

Idaho Statistical Abstract. College of Business and Economics, Bureau of Business and Economic Research, University of Idaho, Moscow, ID 83843

This publication is a compendium of economic, social and political data for the state of Idaho. It is issued irregularly; therefore much of the data may become outdated before a new issue is published. Data sources are listed where more recent and/or more detailed information might be obtained. The next edition will be available in 1979.

CU-502

New Mexico Statistical Abstract. Bureau of Business and Economic Research, University of New Mexico, University Hill NE, Albuquerque, NM 87131

Issued about every seven years, this publication contains social and economic data on the state of New Mexico. Natural resource data is limited but data on employment, income, population and taxes and revenue are more detailed. A section of the book provides county data tables.

CU-503

Oregon Economic Statistics. Bureau of Business Research, University of Oregon, Eugene, OR 97403

An annual publication containing Oregon statistical data on a wide range of subjects, including population, employment, government finances and forests and forest products. Some of the data are presented by county. Additional and/or more detailed information may be obtained from publications or agencies referred to by the source notes.

CU-504

South Dakota Economic and Business Abstract. Business Research Bureau, School of Business, University of South Dakota, Vermillion, SD 57069

"The purpose of this publication is to provide a convenient and practical reference source for the major series of economic and business data for South Dakota." There is no information on forests or the National Forest System but population, employment and income data are available. There are no plans for a reissuing of this publication but more current information may be obtained from South Dakota Facts (SD-501).

CU-505

Statistical Abstract of Utah. College of Business, Bureau of Economic and Business Research, University of Utah, Salt Lake City, UT 84112

Issued approximately every third year, this publication covers a wide variety of data including population, employment, income, government finance, construction and housing, manufacturing and mining. However there is no data on timber production or forest lands. Many statistics are available only for the state as a whole.

CU-506

Wyoming Data Book. College of Commerce and Industry, Division of Business and Economic Research, University of Wyoming, Laramie, WY 82071

The stated objective of this publication "was to obtain comprehensive and detailed coverage of all data sources pertinent to the state, its people, economy, and resources." This publication was last issued in 1972 and therefore much of the data may be outdated for many needs.

CU-507

Labor Trends in U.S. Forest Industry: A Statistical Survey. 1974. Bulletin No. 5. Yale University, School of Forestry and Environmental Studies, New Haven, CT 06520

"This paper provides basic background statistics on the labor problems of United States forest industries. Well-known secondary sources are relied on throughout. The paper contains three major sections; national employment trends, employment and productivity trends in forest industries, and characteristics of the forest industry work force.

CU-508

Timber Supply Projections for the State of Idaho. 1976. Charles Hatch, Gerald Allen, Geoffrey Houck, and Kenneth Sowles. Bulletin No. 15. Forest Wildlife and Range Experiment Station, University of Idaho, Moscow, ID 83843

"Net cubic foot volume timber supply projections for the state of Idaho are given for the period 1975 to 2045. The timber supplies are projected for a given set of yield assumptions and utilization intensities. These projections are presented separately for northern and southern Idaho by each of four ownership groups: National Forest, Other Public, Forest Industries, and Other Private."

CU-509

Cost Ranges for Facility Development in Private Campgrounds. Robert Espesth. Office of Recreation and Park Resources, Department of Leisure Studies, University of Illinois at Urbana-Champaign, Urbana, IL 61801

"These figures were compiled for use by landowners considering the development of a campground. The costs shown in this publication should be used only for general decision making. The figures shown do not represent the possible cost extremes for each facility, only the costs as estimated in todays market." The figures are revised biennially.

CU-510

Nebraska's State and Private Timber Resources. Department of Forestry, University of Nebraska, Lincoln, NE 68588

. Series of publications issued in 1977 or 1978 for most multicounty forest inventory units, reporting "the findings of the forest resource inventory conducted on state and private lands in Nebraska."

CU-511

Utah's Outdoor Recreation Facilities: An Inventory of the Supply. 1976. Michael Dalton and John Hunt. Institute for the Study of Outdoor Recreation and Tourism, Utah State University, Logan, UT 84322

This report is an inventory of outdoor recreation facilities in Utah. It is issued in two volumes, with Volume II containing county totals.

CU-512

Utah' Best of the West: A Report of the Travel Industry. 1976. John Hunt and Gary Cadez. Institute for the Study of Outdoor Recreation and Tourism, Utah State University, Logan, UT 84332

This study contains information about the Utah travel industry. "Data includes total visitors, expenditures, length of stay, attractions visited, accomodations, recreation activities, origin of visitors, party composition, visitor income, type of motor vehicle, and trip purpose" (Institute for the Study of Outdoor Recreation and Tourism, Publications List).

CU-513

Outdoor Recreation Expenditures in Idaho, 1975. 1977. Larry Waldorf. Center for Research, Grants and Contracts, Boise State University, Boise, ID 83725

This study reviews outdoor recreation expenditures in Idaho in 1975. One chapter examines retail expenditures while several chapters survey expenditures by government agencies.

CU-514

Travel Trends in the United States and Canada. Business Research Division, Graduate School of Business Administration, University of Colorado, Boulder, CO 80309

This publication, issued every thre years, contains travel statistics for the United States and Canada, includin outdoor recreation data. Use data on federal and state lands, and visitor ex penditures are among the tables provid

CU-515

Arizona Agricultural Statistics. Depa ment of Agricultural Economics, Colleg of Agriculture, University of Arizona, Tucson, AZ 85721

(Issued cooperatively with the U.S Department of Agriculture, Arizona Cro and Livestock Reporting Service, 230 N First Ave., Phoenix, AZ 85025.)

Annual publication presenting majo agricultural statistics including live stock numbers, production, and prices. Also contains a list of reports issued regularly during the year by the Arizo Crop and Livestock Reporting Service, in cluding the annual Livestock Inventory the annual Cattle Inventory, the annua Sheep and Lambs on Feed, and the month Slaughter and Monthly Price Report.

CU-516

Idaho Forest Productivity Study: Phase II-Economic Analysis. 1978. Kjell Chs topherson, Charles McKetta, Charles Hatch, and E. Lee Medema. Bulletin No 26. University of Idaho, Forest, Wild life and Range Experiment Station, Moscow, ID 83843

This report, using existing forest inventory data, classifies "the commer cial forest stands in Idaho into 117 separate age-class and species composi tion groups. An additional 39 hypotheti cally regenerated stands were formulatd. Separate yield tables were developed fr five levels of management intensity fo each stand. Each of the stands was an lyzed employing both economic and biolg ical management criteria. The biologi cal criteria were based on maximizing long-run financial returns. Under assumptions reflecting reasonable future economic conditions, these two types o

nagement criteria were evaluated. Sen-tivity of the results to deviations in sumed future economic conditions was so assessed." This document comple-nts Timber Supply Projections for the ate of Idaho (CU-508).

CU-517

rvey of Hunters in Oregon. Oregon ate University, Survey Research nter, Corvallis, OR 97331

This report estimates hunter effort, cess rates of hunters, and kill of veral species of game in the various nagement units of Oregon. This survey conducted by the Survey Research Cen- for the Oregon Department of Fish l Wildlife. Up to 1978 this report s issued on an annual basis. In the ture the survey will be conducted on a ennial basis.

CU-518

t Recreation Demand Source Populations Arizona. 1977. Merton Richards and vid King. University of Arizona, hool of Renewable Natural Resources, son, AZ 85721 (Available through TS, PB 268 129.)

"This report describes the results a general population survey of poten-l outdoor recreationists from six and source populations in Arizona. spondent's social and economic charac-istics are presented and the struc-e of their recreational activity ticipation at each of five National est areas is provided. These data e collected as an information base land managers, researchers, and ers interested in the economic demand consumption of natural resources for reational purposes." This report was pared in cooperation with the Rocky ntain Forest and Range Experiment tion.

CU-519

orado Ski and Winter Recreation tistics. Business Research Division, versity of Colorado, Boulder, CO 09

This annual report presents information on the Colorado ski season. The contents of the report may vary slightly but usually include data on winter use visits, characteristics of skiers, inventory of ski facilities and other pertinent information.

CU-520

Timber for Oregon's Tomorrow: An Analysis of Reasonably Possible Occurrences. 1976. John Beuter, K. Norman Johnson, and H. Lynn Scheurman. Research Bulletin 19. Forest Research Laboratory, Oregon State University, Corvallis, OR 97331

"This is an analysis of timber availability in Oregon, now and in the future. The focus is on local areas within the state and what is likely to happen to timber flows in those areas if certain reasonably possible courses of action are followed. This report is intended to give an overview of what was done and a detailed discussion of the results. Many details on data, assumptions, and the mechanics of how the computer model works are omitted. But enough details are presented to provide necessary understanding of what went on in setting up the projections and in making the calculations."

CU-521

Oregon Angler Survey. Oregon State University, Survey Research Center, Corvallis, OR 97331

This report presents the results of a survey that estimates the number of recreation days and catch of licensed anglers in Oregon. This survey has been conducted for 1970, 1972, 1975 and 1977. At this writing plans for conducting similar surveys in the future were unknown. The surveys have been conducted by the Survey Research Center for the Oregon Department of Fish and Wildlife.

CU-522

Preference Survey of Oregon Resident Anglers. 1978. Helen Lowry. Oregon State University, Survey Research

Center, Corvallis, OR 97331

The purpose of this survey was "to determine the preferences of Oregon adult resident anglers for various management alternatives affecting protection of wild stocks, fish stocking, and harvest regulation" and "to determine the number of Oregon adult license holders who actually fish, how much they fish, and in which fisheries." This survey was conducted by the Survey Research Center for the Oregon Department of Fish and Wildlife.

CU-523

Recreational Snowmobiling in California. 1977. W. Johnson and H. Wallace. Information Series in Agricultural Economics No. 77-1. University of California, Davis, Department of Agricultural Economics, Davis, CA 95616

"This publication summarizes results from a survey conducted during Summer 1975 in which registered owners of snowmobiles in California were asked primarily about the use made of snowmobiles by their household during the 1974-75 season." This publication is issued through the University of California, Agricultural Experiment Station. See also CU-527.

CU-524

Off-Road Vehicle Users in Idaho: Distribution and Activity. 1978. John Mitchell, and John Schomaker, and Dennis Propst. Bulletin Number 20. University of Idaho, Forest, Wildlife and Range Experiment Station, Moscow, ID 83843

This publication presents results of a study "which had as its objectives: to determine characteristics of off-road vehicle owners [and] to estimate patterns of off-road vehicle activity."

CU-525

Recreational Use of Snowmobiles Registered in New Mexico. 1977. James Gray and Marie Matthews. Research Report 347. New Mexico Agricultural Experiment Station, New Mexico State University, P.O. Box 3BF, Las Cruces, NM 88003

This publication summarizes result from a survey conducted in 1975 in whic registered owners of snowmobiles in Ne Mexico were asked about the use of sno mobiles by their household during the winter of 1974-75. See also CU-527.

CU-526

Snowmobiling in Utah: Consumer Characteristics and Site Quality. 1979 (In press). John Keith, R. Haws, and H. Fullerton. Utah Agricultural Experiment Station, Utah State University, Logan, UT 84322.

This publication summarizes result from a survey conducted in 1975 in whi registered owners of snowmobiles in Ut were asked about the use of snowmobile by their household during the winter o 1974-75. See also CU-527.

CU-527

Recreation Snowmobiling in the West: Regional Analysis. 1978. John Keith, James Gray, Warren Johnston, and E. Wennergren. Bulletin 498. Utah Agricultural Experiment Station, Utah Stat University, Logan, UT 84322.

"This report summarizes results fr a regional recreation snowmobiling stu in California, New Mexico, and Utah fo the winter of 1974-75. This report is consolidation and summation of the fin ings of the three states' research, ev though each state's research focused o slightly different aspects of snowmobiing." See also CU-523, CU-525, CU-526

CU-528

Participation and Expenditures for Hunting, Fishing and General Rural Outdoor Recreation in Arizona. 1973. Russell Gum, William Martin, Arthur Smith, C. Depping. Research Report 270. Arizon Agricultural Experiment Station, Univesity of Arizona, Tucson, AZ 85721

This report is a part of a study tat has an "objective of determining the ttal economic value of benefits assignale

fish and wildlife in Arizona." This port presents the results of a survey at measured participation and expendi- es of recreationists in 1970 for hunt- , fishing and other outdoor recreation ivities. "The purpose of the other t of the 1970 study is to document total economic value of hunting and shing and other general rural outdoor creational activities" (see CU-529).

CU-529

e Demand For And Value of Hunting, shing and General Rural Outdoor Recrea- on in Arizona. 1974. William Martin, ssell Gum, and Arthur Smith. Techni- l Bulletin 211. Arizona Agricultural periment Station, University of Ari- na, Tucson, AZ 85721

This report is part of a study that s an "objective of determining the al economic value of benefits assign- le to fish and wildlife in Arizona." is report presents "estimates of con- ner benefits for hunting, fishing and neral rural outdoor recreation." The pose of the other part of the study s to present participation and expendi- e data (see CU-528).

CU-530

put-Output Tables for Alaska's Economy: First Look. 1977. Charles Logsdon, nneth Casavant, and Wayne Thomas. lletin 48. Alaska Agricultural Experi- nt Station, University of Alaska, Fair- nks, AK 99701

"The specific objectives of this pub- cation are to: (1) present a first ok in specific detail at the input-out- t tables of the Alaskan economy, there- examining Alaskan interindustry inter- tions and dependencies; and (2) indi- te, via relevant examples, how the in- rmation contained in these typical put-output tables can be used by pri- te and public policymakers."

CU-531

egon's Forest Resources: Their Contri- tion in the State's Economy. 1978. Douglas Brodie, Robert McMahon, and William Gavelis. Research Bulletin 23. Forest Research Labortory, Oregon State University, Corvallis, OR 97331.

"Background data and analysis are provided on Oregon's forest resources, industry, and economy, which includes logs, exports, lumber, plywood, paper, particlewood, recreation, and wildlife. Data includes quantities, areas, employment, payrolls and value added.

CU-532

The Forest Products Industry in Montana, 1976: An Economic Description of the Industry Based on the Montana Forest Industries Data Collection System. 1979. Maxine Johnson, Randle White, and Charles Keegan. (In press). University of Montana, Bureau of Business and Economic Research, Missoula, MT 59812

This publication reports the results of a forest industries survey conducted in cooperation with the U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. Data presented includes estimates of timber products output and plant residues, and employment and income data for the Montana forest industries.

CU-533

Value Added in Sawmill, Post and Fuelwood Enterprises in New Mexico, 1973 and 1974. 1977. James Gray and Burton English. Research Report 344. New Mexico Agricultural Experiment Station, New Mexico State University, P.O. Box 3BF, Las Cruces, NM 88003

"The objectives of this study were 1) to measure value added in the sawmill, post, and fuelwood industries of New Mexico, and 2) to identify the factors associated with value added and to project value added to 1990 for these industries."

Hawaii State Government

HI-501

The State of Hawaii Data Book - A Statis-

tical Abstract. State of Hawaii Department of Planning and Economic Development, P.O. Box 2359, Honolulu, HI 96804

An official summary of statistics on the social, economic and political aspects of Hawaii, the Abstract "closely follows the organization and format of the Statistical Abstract of the U.S., in order to facilitate comparison of Hawaii data with corresponding series for the nation and other jurisdictions."

HI-502

State of Hawaii Department of Land and Natural Resources: Annual Report. State of Hawaii Department of Land and Natural Resources, P.O. Box 621, Honolulu, HI 96809

This annual publication reviews the activities of the Department of Land and Natural Resources and its various divisions, including the Division of Forestry, the Division of Fish and Game, the Division of State Parks, Outdoor Recreation and Historic Sites, Division of Water and Land Development, and Division of Land Development. Relevant data are presented. Additional information is available on request.

HI-503

Employment and Payrolls in Hawaii. Hawaii Department of Labor and Industrial Relations, Research and Statistics Office, 825 Miliani St., Honolulu, HI 96813

This publication, issued annually, is a compilation of covered employment and payroll data by industry and island. Classification of data by industry is by Standard Industrial Classification. A publication with data only for the whole state is issued on a quarterly basis.

HI-801

Hawaii Department of Land and Natural Resources, Division of Fish and Game, 1151 Punchbowl St., Honolulu, HI 96813

The Hawaii Division of Fish and Game collects numerous types of data that are available on request. Information includes harvest data, sport fish catch data on license sales and revenues, number of hunting and fishing days, and population estimates. License data is also presented in State of Hawaii Department of Land and Natural Resources: Annual Report (HI-502).

Idaho State Government

ID-501

Department of Lands Annual Report. State of Idaho, Department of Lands, Statehouse, Boise, ID 83720

Annual report summarizing activities of the past year. Statistical tables show revenues from resource activities on state lands and timber sales from state lands.

ID-502

Idaho Statewide Comprehensive Outdoor Recreation Plan. Idaho Department of Parks and Recreation, Statehouse, Boise, ID 83720

Outdoor recreation plan for Idaho, updated approximately every fifth year containing an evaluation of the demand for and supply of outdoor recreation resources and facilities in Idaho, and a program for the implementation of the plan. This plan is required by the Land and Water Conservation Fund Act of 196[illegible] (Public Law 88-578). At this writing, the last plan was issued for 1977.

ID-503

Idaho Agricultural Statistics. Idaho Department of Agriculture, P.O. Box 79, Boise, ID 83701

(Issued cooperatively with the U.S. Department of Agriculture, Idaho Crop and Livestock Reporting Service, P.O. Box 1699, Boise, ID 83701.)

Annual compilation of crop and livestock production, and livestock inventory and price data for the state of Idaho. Also contains a list of

ports issued regularly during the year the Idaho Crop and Livestock Reporting Service, including the annual Meat [Ani]mal Production, the monthly Cattle on [Fee]d, the monthly Livestock Slaughter, [and] the monthly Agricultural Prices.

ID-504

[Ann]ual Report of the Department of Fish [and] Game. Idaho Department of Fish and [Ga]me, P.O. Box 25, Boise, ID 83707

This annual report summarizes the [act]ivities of the Idaho Department of [Fi]sh and Game. Information presented [in]cludes harvest data, sport fish catch, [lic]ense data and some population statis[tic]s. Additional information is avail[ab]le on request.

ID-801

[Id]aho Department of Parks and Recrea[ti]on, Statehouse, Boise, Idaho 83720

Unpublished visitor use data avail[ab]le upon request. Data for each state [pa]rk is by day use and overnight use.

ID-802

[St]ate of Idaho, Department of Lands, For[es]t Resources Division, Coeur d'Alene, [ID] 83814

Unpublished timber resource data [av]ailable upon request. Data includes [ti]mber harvest and timber inventory [st]atistics for state-owned lands.

ID-803

[Id]aho Department of Employment, P.O. Box [...], Boise, ID 83735.

The Department of Employment collects [se]veral types of data that are available [on] request, including monthly employment [by] industry and county, and quarterly [wa]ges by industry and county.

[Mo]ntana State Government

MT-501

Montana Data Book. State of Montana, Department of Planning and Economic Development, Helena, MT 59601

Last issued in 1970, "The Montana Data Book represents the fulfillment of a continuing need for current reliable statistical information on which to base state planning and development activities, as well as an infinite number of other decision-making tools. The Montana Data Book is a compilation of economic, social, and governmental statistics on the State. It is designed to serve the same general purposes at the state level as the United States Statistical Abstract does at the Federal level." A brief introduction precedes each chapter, providing the important sources of information. For more current information, refer to Montana County Profiles (MT-502).

MT-502

Montana County Profiles. State of Montana, Research and Information Systems Division, Department of Community Affairs, Capital Station, Helena, MT 59601

Profiles, covering socioeconomic data including population, employment and income, are issued approximately every three years for each Montana county.

MT-503

Montana Agricultural Statistics. Montana Department of Agriculture, Airport Way Bldg., West, 1300 Cedar St., Helena, MT 59601

(Issued cooperatively with the U.S. Department of Agriculture, Montana Crop and Livestock Reporting Service, P.O. Box 4369, Helena, MT 59601.)

Annual compilation of crop and livestock production, and livestock inventory and price data for the state of Montana. Also contains a list of reports issued regularly during the year by the Montana Crop and Livestock Reporting Service, including the monthly Livestock Slaughter, the semiannual Cattle Inventory and Calf Crop and the annual Sheep

Inventory and Lamb Crop.

MT-504

Montana Statewide Comprehensive Outdoor Recreation Plan. Montana Department of Fish and Game, Fish and Game Bldg., 1420 E. 6th Ave., Helena, MT 59601

Outdoor recreation plan for Montana, updated approximately every fifth year, containing an evaluation of the demand for and supply of outdoor recreation resources and facilities in Montana and a program for the implementation of the plan. At this writing, the most recent plan was issued in 1978 and also addresses fish and wildlife programs. This plan is required by the Land and Water Conservation Fund Act of 1965 (Public Law 88-578).

MT-505

Fiscal Year Annual Report. Montana Department of Fish and Game, Recreation and Parks Division, Fish and Game Bldg., 1420 E. 6th Ave., Helena, MT 59601

Annual report that has some data on visitor usage in the Montana State Park System, and revenues from recreation activities on these lands. However at this writing use data is not collected on a regular basis.

MT-506

Montana Historical Energy Statistics. Montana Energy Office, Capitol Station, Helena, MT 59601

Energy data for Montana are presented in this publication. Energy production and consumption are among the subjects covered. At this writing, plans are to update this report annually.

MT-507

Montana Department of State Lands: Statistical Report. Montana Department of State Lands, Capitol Bldg., Helena, MT 59601

This biennial report contains data summarizing activities of the Department of State Lands. Information presented includes income from grazing and mineral leases.

MT-508

Montana Economic Indicators. Department of Labor and Industry, Employment Security Division, Research and Analysis Section, P.O. Box 1728, Helena, MT 59601

This quarterly publication summarizes economic data relating to Montana. Data presented include employment and earnings.

MT-509

Montana Employment and Labor Force. Montana Department of Labor and Industry, Employment Security Division, P.O. Box 1728, Helena, MT 59601

This monthly publication is a compilation of employment earnings data by industry and county. Classification of data by industry is by Standard Industrial Classification.

MT-801

State of Montana, Department of Natural Resources and Conservation, Forestry Division, 2705 Spurgin Rd., Missoula, MT 59801

Unpublished timber resource data available upon request. Data include timber harvest statistics for state and private lands. At this writing, the Forestry Division is in the process of inventorying state and private lands.

MT-802

Montana Department of Fish and Game, Fish and Game Bldg., 1420 E. 6th Ave., Helena, MT 59601.

The Montana Department of Fish and Game collects numerous types of data that are available on request, including harvest information, license sales and revenues, and number of hunting days.

braska State Government

NE-501

braska Statistical Handbook. Nebraska partment of Economic Development, Box 66, State Capital, Lincoln, NE 68509

A biennial publication incorporating a on demographic, social, physical and nomic aspects of the State. Source ces denote the publication or agency ere supplementary information may be ained.

NE-502

ual Report. Nebraska Game and Parks mmission, P.O. Box 30370, Lincoln, NE 503

This annual publication reviews the tivities of the Nebraska Game and Parks mmission and its various divisions cluding the Fisheries Division, the rks Division, and the Wildlife Divi- on. General data for these, and other visions are presented. Additional formation is available on request.

NE-503

braska State Comprehensive Outdoor creation Plan. Nebraska Game and rks Commission, P.O. Box 30370, ncoln, NE 68503

Outdoor recreation plan for Nebras- , updated approximately every fifth ar, containing an evaluation of the mand for and supply of outdoor recrea- on resources and facilities in Nebras- and a program for the implementation this plan. At this writing, the most cent plan was issued in 1978. This an is required by the Land and Water nservation Fund Act of 1965 (Public w 88-578).

NE-504

braska Agricultural Statistics. Ne- aska Department of Agriculture, P.O. x 94844, Lincoln, NE 68509

(Issued cooperatively with the U.S. Department of Agriculture, Nebraska Crop and Livestock Reporting Service, P.O. Box 81069, Lincoln, NE 81069.)

Annual compilation of crop and live- stock production, and livestock inventory and price data for the state of Nebraska.

NE-801

Nebraska Department of Labor, Division of Employment, P.O. Box 94600, Lincoln, NE 68509.

The Division of Employment collects several types of data that are available on request, including monthly employment by industry and county, and quarterly wages by industry and county.

New Mexico State Government

NM-501

New Mexico Agricultural Statistics. New Mexico Department of Agriculture, New Mexico State University, P.O. Box 3189, Las Cruces, NM 88003

(Issued cooperatively with the U.S. Department of Agriculture, New Mexico Crop and Livestock Reporting Service, P.O. Box 1809, Las Cruces, NM 88001.)

Annual compilation of crop and live- stock production statistics, and income and price data for the State of New Mexico. Also contains a list of reports issued regularly during the year by the New Mexico Crop and Livestock Reporting Service, including Annual Livestock Inventory and Annual Sheep and Lambs.

NM-502

State and Private Forest Resources. New Mexico Department of State Forestry, P.O. Box 2167, Santa Fe, NM 87503

Series of publications summarizing the findings of a timber resource inventory of State and private lands in New Mexico, due to be completed in 1980. Each publication has data for an individual county or a group of counties.

NM-503

New Mexico Department of Game and Fish: Annual Report. New Mexico Department of Game and Fish, State Capitol, Santa Fe, NM 87503

This annual publication reports on the activities of the New Mexico Department of Fish and Game. Harvest and license data are included in this report. See also NM-802.

NM-504

Covered Employment and Wages. New Mexico Department of Human Sevices, Employment Services Division, P.O. Box 1928, Albuquerque, NM 87103

This publication, issued quarterly, is a compilation of covered employment and payroll data by industry and county. Classification of data by industry is by Standard Industrial Classification.

NM-801

New Mexico Department of State Forestry, P.O. Box 2167, Santa Fe, NM 87503

Unpublished data, available on request on timber harvests and sales on New Mexico State lands. Timber resource inventory data for state and private lands in greater detail than published reports (see NM-502) are also available.

NM-802

New Mexico Department of Fish and Game, State Capitol, Santa Fe, NM 87501

The New Mexico Department of Fish and Game collects various types of data that are available upon request. Much of the information is in internal performance reports or in reports resulting from the Federal Aid in Fish and Wildlife Restoration program and includes harvest data, population estimates, numbes of hunters and fishermen, and license data. See also NM-503.

NM-803

New Mexico Natural Resources Department, Park and Recreation Division, P.O. Box 1147, Santa Fe, NM 87503

The New Mexico Park and Recreation Division collects several types of data that are available on request, including State park visitation data, inventories of recreation facilities, and State revenue from user fees.

Nevada State Government

NV-501

County Datafiles. State of Nevada, Department of Economic Development, Carson City, NV 89701

These are a series of pamphlets issued irregularly, one for each county in Nevada, containing basic statistical data.

NV-502

Recreation in Nevada-Statewide Comprehensive Outdoor Recreation Plan. Department of Conservation and Natural Resources, Nevada State Park System, Capitol Complex, 201 South Fall St., NYE Bldg., Room 221, Carson City, NV 89710

Outdoor recreation plan for Nevada, updated continually, containing an evaluation of the demand for and supply of outdoor recreation resources and facilities in Nevada, and a program for the implementation of the plan. This plan is required by the Land and Water Conservation Fund Act of 1965 (Public Law 88-578). At this writing, the last plan was issued for 1977.

NV-503

Nevada State Park Survey. Department of Conservation and Natural Resources, Nevada State Park System, Capitol Complex, 102 South Fall St., NYE Bldg., Room 221, Carson City, NV 89710

The Nevada State Park System conducts visitor surveys on an irregular basis, that appraise socioeconomic data, State park use data and user comment data.

NV-504

ada Agricultural Statistics. Nevada te Department of Agriculture, P.O. 11100, Reno, NV 89510

(Issued cooperatively with the U.S. artment of Agriculture, Nevada Crop Livestock Reporting Service, P.O. 8888, Reno, NV 89507, and the University of Nevada, Division of Agriculture and Resource Economics, Reno, NV 57.)

Annual compilation of crop and estock production, and livestock entory and price data for the State Nevada.

NV-505

nnial Report: Nevada Department of h and Game. Nevada Department of h and Game, P.O. Box 10678, Reno, NV 10

This biennial report summarizes the ivities of the Nevada Department of h and Game. General data on license fee revenue, harvest information, ulation estimates and number of ters and fishermen are presented. e specific detailed reports on these related subjects are also available.

NV-506

loyment and Payrolls. Nevada Employ-t Security Department, 500 East 3d , Carson City, NV 89713

This publication, issued annually, a compilation of covered employment payroll data by industry and county. ssification of data by industry is by ndard Industrial Classification.

NV-801

ada Department of Conservation and ural Resources, State Park System, itol Complex, 201 South Fall St., NYE g., Room 221, Carson City, NV 89710

Unpublished data available upon uest, dealing with State park use a on a monthly or annual basis and revenue generated from recreation activities.

Oregon State Government

OR-501

State Parks Visitor Survey: Summary Report. Oregon State Parks and Recreation Branch, 525 Trade Street S.E., Salem, OR 97310

"The Oregon State Parks Visitor Survey is undertaken periodically by the Parks and Recreation Branch, Department of Transportation, to obtain information which will be used:

- To identify recreational characteristics and needs of state park visitors;
- To establish state park policies;
- To plan future state park facilities and services;
- To determine economic effects of state parks on nearby communities and regions; and
- To provide recreation demand data for the State Comprehensive Recreation Plan."

Highlights of the survey are included in the summary reports. Further information about survey findings is available from the Parks and Recreation Branch.

OR-502

Biennial Report of the State Forester. State of Oregon, Department of Forestry, 2600 State St., Salem, OR 97310

Summarizes key programs in the Oregon Department of Forestry. A supplement has relevant statistical data. See also the abstract for Forest Resource Data Catalog in the Additional Sources section.

OR-503

Annual Report: Wildlife Division.

Oregon Department of Fish and Wildlife, P.O. Box 3503, Portland, OR 97208

This annual report summarizes the activities of the Wildlife Division. Information presented includes population trends and harvest data. Additional information is available on request. See also Annual Survey of Hunters in Oregon (CU-517).

OR-504

Annual Report: Fisheries. Oregon Department of Fish and Wildlife, P.O. Box 3503, Portland, OR 97208

This annual report summarizes the activities of the Fish Division and fish-related activities by other sections of the Department. Information presented includes commercial fish catch and sport fish catch. Additional information is available on request. See also CU-521 and CU-522.

OR-505

Oregon Covered Employment and Payrolls by Industry and County. Oregon Department of Human Resources, Employment Division, Research and Statistics Section, 875 Union St., N.E., Salem, OR 97311

This publication, issued quarterly, is a compilation of covered employment and payroll data by industry and county. Classification of data by industry is by Standard Industrial Classification. An annual summary volume is also issued.

OR-801

Oregon State Parks and Recreation Branch, 525 Trade Street S.E., Salem, OR 97310

Unpublished recreation data available upon request. At this writing, data categories include:

1) "Oregon State Parks and Waysides" --Brief description of each state park and wayside including acre age, location and facilities.

2) "Overnight Camping: Maintenance Expenditures Compared to Revenue" --Compares expenses and revenues by park.

3) "Gross Cost Per Day Use Visitor" --Lists day visitors, maintenanc costs and cost per visitor by re gion and park.

4) "Net and Gross Cost Per Campernight"--Lists gross cost per cam pernight and net cost per camper night as a function of maintenance cost, revenue, net cost, campernights.

5) "Revenue: Park User Fees"--User revenues by source and park.

6) "Day Visitor Attendance"--Tables for past years of day visitor at tendance by park.

7) "Overnight Camping by the Public --Tables for past years of campe-nights by region and park.

8) "Overnight Camp Occupancy, Occupancy Rate of Spaces Available" --Number of camping sites and monthly occupancy rate, by regio and park.

9) "Camper Origin Report Summary"-- Individual park data on number o campnights and origin of campers by various geographical entitie (e.g., Oregon counties, California, Rocky Mountain, etc.).

Private Organizations

PR-501

Arizona Statistical Review. Valley National Bank of Arizona, Economic Research Department, P.O. Box 71, Phoenix, AZ 85001

This annual publication is a collection of economic statistics for the State of Arizona. The book also contains economic profiles of all Arizona counties

PR-502

California County Fact Book. County

ervisors Association of California, te 201- 11 and L Building, Sacramento, 95814

This is an annual publication with tistical information on economic, sical and political aspects of the 58 ifornia Counties. The nature of this lication, i.e., "county facts", gen-lly makes it more valuable than the ifornia Statistical Abstract (CA-501), ause data is presented by county. As the California Statistical Abstract, a sources are provided as well as a t of source contributors and their resses where further information may obtained.

PR-503

tistical Abstract of Colorado. Trans- Bibliographics, P.O. Box 22678, Den-, CO 80222

Initially published in 1977, this k "is an unofficial summary of statis-s about the state of Colorado--its ulation, resources, environment, and ernment institutions." At this writ- it is unkown if and when this publi-ion will be updated. This edition ludes chapters on population, housing, lic lands and recreation, governments, loyment, mining and forestry.

PR-504

Research Council's Handbook. Wash-ton State Research Council, 1069 Capi- Way, Olympia, WA 98501

A periodical compendium of statisti- and explanatory information about te and local government in Washington, formation is presented for those as-ts of state and local government ich are most important in terms of ple served and/or public funds invol-. In addition, the Handbook contains tain population, income and economic a frequently referred to in discus-ons of governmental activities." This lication is useful for State and al government data but contains no formation about general State employ-t, the private sector or forest re-rces.

PR-505

Random Lengths Yearbook. Random Lengths Publications, Inc., P.O. Box 867, Eugene, OR 97401

"Published each January, the Yearbook provides a record of 150 items of lumber, plywood, shingles, shakes, veneer and particleboard for the past 10 years. There are graphs of prices for the past five years. Seasonal trends are shown in prices averaged monthly over a five year period. Rounding out this valuable reference are yearly market summaries, future market summaries, production statistics, log export volumes, monthly housing starts and sanded plywood prices."

PR-506

Random Lengths Weekly Market Report and Price Guide. Random Lengths Publications, Inc., P.O. Box 867, Eugene, OR 97401

"This 12-page report on lumber and plywood markets is published each Friday. It contains market summaries on the major North American species and pinpointed prices on more than 1,000 items in both straight and mixed car assortments."

PR-507

Random Lengths Midweek. Random Lengths Publications, Inc., P.O. Box 867, Eugene, OR 97401

"For those who need more frequent coverage of prices and markets, the Midweek Report is published each Tuesday at the close of the business day. The report covers key items of dimension lumber, studs, boards and plywood. Transmitted by overnight Mailgram or by mail."

PR-508

Random Lengths Export. Random Lengths Publications, Inc., P.O. Box 867, Eugene, OR 97401

"Export is published biweekly giving the latest news of U.S. and Canadian

overseas markets. It includes developments in international timber trading, stressing prices on major North American items of lumber and plywood. Price studies, marketing surveys and changing patterns in production and distribution are featured."

PR-509

Random Lengths Stud Buyers' Guide. Random Lengths Publications, Inc., P.O. Box 867, Eugene, OR 97401

"Random Lengths Stud Buyers' Guide lists 125 stud producers in the U.S. and Canada, a separate listing of companies by producing regions, a directory of sales managers, reference charts for species and specialty items produced by each company, and complete results of The Random Lengths survey of stud production and marketing."

PR-510

Random Lengths Board Buyers' Guide. Random Lengths Publications, Inc., P.O. Box 867, Eugene, OR 97401

"The Random Lengths Board Buyers' Guide provides complete board survey results, alphabetical listings of board producing firms, as well as regional listings of companies. Also included are reference charts for species and specialty items. In addition, the guide contains the complete results of the Random Lengths survey of board production and marketing."

PR-511

Random Lengths Telex Service. Random Lengths Publications, Inc., P.O. Box 867, Eugene, OR 97401

"For those who need immediate reports on lumber and plywood markets, Random Lengths offers twice-weekly price reports via the Random Lengths Telex Service. Released on Friday and Tuesday, Telex Service offers the option of receiving all or any one of the reports --the Friday Lumber Report, the Friday Plywood Report or the Tuesday Midweek Report. The Random Lengths Telex Service is available only to subscribers.

PR-512

Yearbook of Forest Products. Forestry Department, Statistics and Economic Analysis Unit, Food and Agriculture Organization of the United Nations, Via dell Terme D, Caracalla 00100 Rome, Italy

This annual publication containing annual data on the global production and trade in forest products, has been arranged in three parts. "The first part contains tables dealing with the volume of production and the volume and value of trade. The second part contains tables dealing with the direction of trade. The third part contains tables showing the unit value in trade of some commodities."

PR-513

Monthly Report of Redwood and Whitewood Production, Shipment, Orders and Stock. California Redwood Association, 1 Lombard St., San Francisco, CA 94111

This report includes redwood and whitewood production and distribution f redwood shipments and orders received (including exports).

PR-514

Fingertip Facts and Figures. National Forest Products Association, 1619 Massachusetts Avenue N.W., Washington, D.C. 20036

A monthly report on general forest products data. Data includes production, trade statistics, construction and housing statistics and economic indicators.

PR-515

Western Lumber Facts. Western Wood Products Association, Yeon Bldg., Portland, OR 97204

A monthly report on western lumber data. Data includes production and shipments, average F.O.B. mill realization and labor facts.

PR-516

Employment Summary. Western Wood Products Association, Yeon Bldg., Portland, OR 97204

"This (semiannual) summary represents operations within the softwood lumber producing region represented by the Western Wood Products Association." Data includes number of employees, average hourly earnings and average hours of employment.

PR-517

Lumber Price Trends - Inland Mills. Western Wood Products Association, Yeon Bldg., Portland, OR 97204

Issued monthly, "these index prices reflect the trend of weighted prices for the entire area producing in land species. The grade percentages used are based upon the Association's analyses of realization of the various grades for each species in the year shown. Index levels are estimated to be representative of market levels experienced five to nine weeks prior to publication."

PR-518

Monthly Pulpwood Summary. American Pulpwood Association, 1619 Massachusetts Ave., N.W., Washington, DC 20036

A monthly review of pulpwood statistics including receipts, consumption and inventory, by state.

PR-519

Statistics of Paper and Paperboard. American Paper Institute, 260 Madison Ave., New York, NY 10016

An annual publication presenting a statistical picture of the paper and paperboard industry. In addition to statistics on production, imports, exports consumption, finances, government reports on prices, employment and wage rates, this report compares trends in apparent consumption of paper and paperboard, by major grades, with trends in population and in total economic activity as measured by the real Gross National Product."

PR-520

Sunset Western Campsites. Lane Publishing Co., 85 Willow Rd., Menlo Park, CA 94025

An annual compendium of all public and private campsites in the Far West of the United States, Baja California and Western Canada. Listings include location, fees, activites (e.g., swimming), and conveniences (e.g., showers). Opening and closing dates of seasonal campgrounds are indicated as well as the need for reservations. A related publication is Sunset Campsite Directory encompassing the entire United States; however there are no plans to update this publication.

PR-521

Campground and Trailer Park Guide. Rand McNally and Company, 206 Sansome St., San Francisco, CA 94104

An annual guide to public and private campgrounds of North America. Listings include location, capacity, fees, opening and closing dates, facilities and activities.

PR-522

Inventory of Private Recreation Facilities, 1977. 1977. National Association of Conservation Districts, 1025 Vermont Ave. N.W., Washington, DC 20005

This study, done in cooperation with the Soil Conservation Service, U.S. Department of Agriculture, and the Bureau of Outdoor Recreation (renamed the Heritage, Conservation and Recreation Service in 1978), U.S. Department of the Interior, is a private sector recreation inventory. The publication includes individual state summaries by activity and enterprise. More detailed information (e.g., county information) can be obtained through each state soil conservation agency, state offices of the Soil Conservation Service or state agencies responsible for the outdoor recreation

program.

Note: At this writing a nationwide study called An Assessment of the Use and Potential of Private Lands for Outdoor Recreation, is underway. The study is assessing "current and potential uses of private rural lands which will lead to an up-to-date information system of the private sector and its resources. The immediate application of this research will be to develop private sector recreation supply data" (U.S. Department of Commerce, Statistical Reporter, No. 78-2, November 1977). For further information contact H. K. Cordell, U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station, Carlton St., Athens, GA 30602

PR-523

The Sporting Goods Market. The National Sporting Goods Association, 717 North Michigan, Chicago, IL 60611

Annual report dealing with output, consumer expenditures and prices of sporting goods.

PR-524

National Travel Survey: Full Year Report. U.S. Travel Data Center, 100 Connecticut Ave. N.W., Washington, DC 20036

Annual report, on travel activity in the United States, except for years ending in "2" and "7" when the Bureau of Census conducts the Census of Transportation: National Travel Survey (see US-587).

PR-525

National Travel Survey: Quarterly Reports. U.S. Travel Data Center, 100 Connecticut Ave., NW, Washington, DC 20036

Quarterly reports on travel activity in the United States. These reports are not issued for years ending in "2" and "7" when the Census of Transportation: National Travel Survey (US-587) is taken.

PR-526

National Travel Expenditure Study: Summary Report. U.S. Travel Data Center, 100 Connecticut Ave. N.W., Washington, DC 20036

Annual report providing detailed estimates of the expenditures of U.S. residents for travel within the United States.

PR-527

Statistical Yearbook. Western Wood Products Association, 1500 Yeon Bldg., Portland, OR 97204

Annual compendium of forest product data, lumber production statistics and amounts of imports and exports in the Western U.S.

PR-528

State Park Statistics. National Recreation and Park Association, 1601 N. Kent St., Arlington, VA 22209

Issued approximately every five years, this publication summarizes all State park statistics, including use data, visitor expenditures, and State park administrative agencies revenues and expenditures. This report was previously issued by the National Park Service and the Bureau of Outdoor Recreation.

PR-529

1976 Ski Travel and Vacation Survey. Ski Magazine, 380 Madison Ave., New York, NY 10017

Survey taken of a random sample of Ski Magazine subscribers, examining their skiing activities. Similar studies will be done in the future.

PR-530

The White Book of U.S. Ski Areas. Inter-Ski Services, P.O. Box 3635, Georgetown Station, Washington, DC 20007

This publication is an inventory of
. ski areas. Information on each fa-
ity is listed, including the length
the season, lift rates, lift capacity
hour and the availability of addi-
nal recreation facilities, lodging
ilities and restaurants. At this
ting, plans are to update this publi-
ion on an annual basis.

PR-531

rgy Use in the United States by State
l Region. 1978. Irving Hoch. Re-
urces for the Future, Inc., 1755 Mas-
chusetts Ave., N.W., Washington, DC
036

"This report contains a compendium
statistics on U.S. energy use by state
l region in 1972, some applications of
ose statistics in describing the role
energy in subnational economies, and
e critical evaluations of the adequacy
those statistics. This report pre-
nts information on energy consumption,
enditures and prices using three sys-
ms of classification, respectively in-
lving energy source, function and
ctor.

PR-532

ear) Annual Ski Lift Revenue Survey
l Regional Analysis. Mel Borgersen
l Associates, Ltd., Skinner Bldg.,
attle, WA 98101

This annual publication contains data
lift revenues at selected western
rth American ski areas.

PR-533

ends in Natural Resource Commodities:
atistics of Prices, Output, Consump-
on, Foreign Trade, and Employment in
e United States, 1870-1957. 1962.
al Potter and Francis Christy. Re-
rces for the Future, Inc., 1755
ssachusetts Ave., N.W., Washington,
20036

This volume presents "comprehensive
nsistent long-term series for the
incipal economic aspects of major
tural resource commoditites, from
which (the authors) have derived aggregate measures for all resources and for major groups of resources."

PR-534

Monthly Statistical Summary. American Paper Institute, 260 Madison Ave., New York, NY 10016

This monthly publication has summary statistics on pulp and paperboard, including production figures, whole price indexes and trade data.

PR-535

U.S. Skiing Market Report. 1978. Ski Industries America, 1200 17th St. N.W., Washington, DC 20036

This report presents information about the skiing industry including skiing frequency, ski trips and socioeconomic characteristics of skiers. This study was conducted for Skiing Magazine by Opinion Research Corporation.

PR-536

Energy in the World Economy: A Statistical Review of Trends in Output, Trade, and Consumption Since 1925. 1971. Joel Darmstadter et al. Resources for the Future, Inc., 1755 Massachusetts Ave., N.W., Washington, DC 20036

"This book deals with quantitative aspects of long-term trends in energy consumption, production, and foreign trade. (The book assembles) statistical series depicting movements in consumption, production, and international trade of energy commodities since 1925 by countries, regions, and the world as a whole."

PR-801

Kampgrounds of America, Inc., P.O. Box 30558, Billings, MT 59114

Kampgrounds of America conducts occasional surveys dealing with camping. Among the factors examined are the number of nights camped out, the geographic

dispersion of campers, and various socio-economic characteristics, including age and income.

PR-802

National Campground Owners Association, RFD 2, Martinsville, IL 62442

The National Campground Owners Association, the national trade association of the commercial campground industry, conducts occasional surveys of their members. Survey questions include capacity and use of campgrounds, and campground revenues.

COMPUTER TAPES

PR-901

National Travel Survey: Quarterly Tapes, U.S. Travel Data Center, 100 Connecticut Ave. N.W., Washington, DC 20036

Quarterly issued computer tapes on travel activity in the United States. Tapes are not issued for years when the Census of Transportation: National Travel Survey is taken (years ending in "2" and "7"). See US-587 and US-901 for information on the Census of Transportation: National Travel Survey, and PR-524, PR-525 and PR-902 for further information on U.S. Travel Data Center's surveys.

PR-902

National Travel Survey: Full Year Tape. U.S. Travel Data Center, 100 Connecticut Ave. N.W., Washington, DC 20036

Annually issued tapes on travel activity in the United States. Tapes are not issued for years when the Census of Transportation: National Travel Survey is taken (years ending in "2" and "7"). See US-587 and US-901 for information on the Census of Transportation: National Travel Survey, and PR-524, PR-525 and PR-901 for further information on U.S. Travel Data Center's surveys.

South Dakota State Government

SD-501

South Dakota Facts. Office of Executiv Management, South Dakota State Planning Bureau, Pierre, SD 57501

This publication was issued in 1976 with no immediate plans for an updated version. "South Dakota Facts contains broad variety of data on the people, re- sources, agriculture and economy of Sou Dakota. Data are presented for the state, counties and planning and develo ment districts."

SD-502

South Dakota Comprehensive Outdoor Recreation Plan. South Dakota Department of Game, Fish and Parks, Division of Parks and Recreation, Pierre, SD 57501

Outdoor recreation plan for South Dakota, updated approximately every fou years, containing an evaluation of the demand for and supply of outdoor recrea tion resources and facilities in South Dakota and a program for the implementa tion of the plan. This plan is require by the Land and Water Conservation Fund Act of 1965 (Public Law 88-578) and was last revised, as of this writing, in 1975.

SD-801

South Dakota Department of Game, Fish and Parks, Division of Parks, Sirgud Anderson Bldg., Pierre, SD 57501

Various kinds of data are available on request from the various divisions c the Department, including the Game and Fish Division, Parks and Recreation Div- sion, and the Forestry Division. The Parks and Recreation Division collects visitation and revenue data for South Dakota State Parks. The Game and Fish Division collects harvest data and license data. Also worth mentioning are the following two reports, prepared by the University of South Dakota in cooperation with the Division:

1) The Economic Impact of Sport Fishing in South Dakota, 1972,

With Notes on Angler Traits. 1973. A.A. Volk and V.E. Montgomery.

2) Hunting in South Dakota, 1973. 1974. A.A. Volk and V.E. Montgomery. Bulletin 112.

SD-802

[illegible]th Dakota Department of Labor, 607 [illegible]th 4th St., Aberdeen, SD 57401

The Department of Labor collects [illegible]eral types of data that are available on request, including employment [illegible] wages by industry and county.

[illegible]ited States Government

US-501

[illegible]tistical Abstract of the United [illegible]tes. U.S. Department of Commerce, [illegible]eau of the Census, Washington, DC [illegible]33

This annual publication "is the [illegible]ndard summary of statistics on the [illegible]ial, political and economic organi[illegible]ion of the United States. It is de[illegible]ned to serve as a convenient volume [illegible] statistical reference and as a guide [illegible] other statistical publications and [illegible]rces." The Statistical Abstract is [illegible]marily for national data, but many [illegible]les present data for regions and indi[illegible]ual states and a smaller number for [illegible]ropolitan areas and cities. The [illegible]cent Trends" section which includes [illegible]a on population, employment and wood [illegible] mineral production is also available [illegible]arately in a reprint "Recent Social [illegible] Economic Trends." For a historical [illegible]pendium see Historical Statistics of [illegible] United States, Colonial Times to [illegible]ar) (US-606).

US-502

[illegible]nty and City Data Book. U.S. Depart[illegible]t of Commerce, Bureau of the Census, [illegible]hington, DC 20233

This periodical publication "presents a variety of statistical information for counties, standard metropolitan statistical areas, cities, urbanized areas and unincorporated areas." Data on population, employment, income, housing and other matters are presented in a complete and comprehensive form.

US-503

Production, Prices, Employment and Trade in Northwest Forest Industries. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, P.O. Box 3141, Portland, OR 97208

"This quarterly report presents current information on the timber situation in Alaska, Washington, Oregon, California, Montana, Idaho, and British Columbia, including data on lumber and plywood production and prices; timber harvest; employment in forest products industries; international trade in logs, pulpwood, chips, lumber, and plywood; log prices in the Pacific Northwest; volume and overage prices of stumpage sold by public agencies; and other related items. The statistical data are from secondary sources and are brought together to make such information more readily available. Sources are indicated for each table and can be contacted directly for means used in data collection."

US-504

The Demand and Price Situation for Forest Products. U.S. Department of Agriculture, Forest Service, Forest Economics and Marketing Research Staff, P.O. Box 2417, Washington, DC 20013

This report, issued approximately every two years, "presents information on trends in production, trade, consumption, and prices of forest products in the United States. Although national trends are dealt with for the most part, some material is given for regions and states."

US-505

Agricultural Statistics. United States Department of Agriculture, Washington, DC 20250

"Agricultural Statistics is published each year to meet the diverse needs for a reliable reference book on agricultural production, supplies, consumption, facilities, costs and returns. Its tables of annual data cover a wide variety of facts in forms suited to most common use." Included is a general section on forest statistics provided by the Forest Service.

US-506

The Outlook for Timber in the United States. 1974. U. S. Department of Agriculture, Forest Service, P.O. Box 2417, Washington, DC 20013

"This report on the Nation's timber-supply and demand situation and outlook relates primarily to the 500 million acres of commercial timberland in the United States that are suitable for production of timber crops. It provides an analysis of the Nation's timber situation as of 1970 and the outlook under a number of economic and management alternatives. This study includes statistical data as of 1970 on the current area and condition of the Nation's forest land, inventories of standing timber, and timber growth and removals by individual States. Information is also included on recent trends in forest land and timber resources, trends in utilization of the Nation's forests for timber and other purposes, and trends in consumption of wood products. Data are also presented on foreign sources of timber and foreign markets for U.S. products. Projections of future demands for timber in the U.S. indicate market potentials under a range of economic and price assumptions. Projections of timber supplies point to prospective and potential availability of wood products with alternative levels of forest management and utilization, and alternative price trends."

US-507

U.S. General Imports: Schedule A, Commodity by Country. U.S. Department of Commerce, Bureau of Census, Washington, DC 20233

"Detailed monthly report on the quantity and value of U.S. commodity imports by individual countries of origin. Data are compiled by the Census Bureau from U.S. customs import documents. Reports are issued 3-6 months after month of coverage. All tables give data for the current month and year to date." (Congressional Information Service. 1976. American statistics index second annual supplement: abstracts. p. 212) Data includes value of commodities and value and quantity of commodity, by country of origin, customs value, free alongside ship and cost, insurance and freight valuation.

US-508

U.S. Exports: Schedule B, Commodity by Country. U.S. Department of Commerce, Bureau of Census, Washington, DC 20233

"Detailed monthly report on the quantity and value of U.S. commodity exports by individual countries of destination. Data are collected through the Shippers Export Declaration by customs officials Reports are issued 2-4 months after month of coverage. All tables give data for the current month and year to date." (Congressional Information Service. 1976. American statistics index second annual supplement: abstracts. p. 212). Data includes value of commodities and commodity by country.

US-509

Wood Products Used in the Construction of Nonresidential and Nonhousekeeping Buildings - United States, 1961, 1969 and 1973. 1977. William Reid. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, P.O. Box 5130, Madison, WI 53705

This report presents estimates "of the amounts of lumber, glued-laminated lumber, plywood, hardboard, particleboard, insulation board, and structural wood-fiberboard used in nonresidential and nonhousekeeping building construc-

in in the United States during 1961, 99, and 1973. Amounts of all products r stratified by building type and tuctural class. In addition, lumber n plywood are stratified by region and tuctural component."

US-510

cd Used in Manufacturing Industries, 95. 1969. T.G. Gill and R.B. Phelps. . Department of Agriculture, Forest evice, Division of Forest Economics r Marketing Research, P.O. Box 2417, ahington, DC 20013

"This report presents information on h volume of lumber, plywood, veneer, dboard, particleboard, and bolts used r manufacturing industries in 1965. ales showing the amounts reported by h 127 industries and amounts estimated c have been used by all 423 industries r 1965 are included within the text. h data presented in the detailed ap- edix tables are based on the 127 eorting industries and have not been justed for full industry coverage." n updated report on this subject is ected to be issued in 1979.

US-511

ber Cut and Sold. U.S. Department of iculture, Forest Service, Division of ber Management

Quarterly and annual reports issued y each Forest Service region (see App.) containing data on timber cut and d on national forest lands. Data, by est, includes volume and dollar value timber sold and timber cut by conver- le and nonconvertible products and ber of sales made.

US-512

port of the Chief, Forest Service. . Department of Agriculture, Forest vice, P.O. Box 2417, Washington, DC 13

Prior to 1978, the annual report by Chief of the Forest Service to the retary of Agriculture on the major grams and accomplishments of the Forest Service. Data on major resource activities are presented in statistical tables. The data categories vary from year to year. This series was replaced in 1978 by Report of the Forest Service (US-595).

US-513

Land Areas of the National Forest System. U.S. Department of Agriculture, Forest Service, P.O. Box 2417, Washington, DC 20013

An annual compendium of the areas of the National Forest System divided into a number of categories including regions, states and counties and special land classifications.

US-514

Annual Grazing Statistical Report, Use Survey. U.S. Department of Agriculture, Forest Service, P.O. Box 2417, Washington, DC 20013

This annual report summarizes the use of National Forest land for grazing cattle, horses, sheep and goats. Tables are divided into national, regional and state use.

US-515

National Survey of Hunting, Fishing and Wildlife - Associated Recreation. U.S. Department of the Interior, Fish and Wildlife Service, Washington, DC 20242

This report, issued every five years, has statistics on hunting and fishing activities, wildlife observation, wildlife photography, recreational shooting, and crabbing and clamming. The published report contains only national data, but individual state data is available by requesting the particular state or states desired. State tables follow the same format as national tables.

US-516

State Government Tax Collections. U.S. Department of Commerce, Bureau of the Census, Washington, DC 20233

Data on state tax collections and rates are presented in this annual report. Tables include state tax revenue, state individual income taxes, and state tax collections.

US-517

Taxes and Intergovernmental Revenue of Counties, Municipalities and Townships. U.S. Department of Commerce, Bureau of the Census, Washington, DC 20233

"Annual report on general revenues of counties, municipalities, and townships, including total and per capita amounts by state, type of tax and specified intergovernmental source" (Congressional Information Service. 1977. American statistics index third annual supplement: abstracts. p. 274).

US-518

State Government Finances. U.S. Department of Commerce, Bureau of the Census, Washington, DC 20233

"Annual report presenting detailed data on State government finances. Shows data on expenditures by function, revenue by source, indebtedness and debt transactions, as sets and others" (Congressional Information Service. 1977. American statistics index third annual supplement: abstracts. p. 273).

US-519

City Government Finances. U.S. Department of Commerce, Bureau of the Census, Washington, DC 20233

"Annual report presenting detailed financial data on city governments, including separate breakdowns for governments of hundreds of cities and towns of 50,000 or more" (Congressional Information Service. 1977. American statistics index third annual supplement: abstracts. p. 273). Data includes revenue by source, and expenditure by function.

US-520

Government Finances. U.S. Department of Commerce, Bureau of the Census, Washington, DC 20233

"Annual report presenting detailed data on finances of Federal, State, and local government. Covers revenue by source, expenditure by function" (Congressional Information Service. American statistics index third annual supplement: abstracts. p. 273.). Tables include revenue by source and level of government, federal revenue sharing and expenditures by source and level of government.

US-521

Local Government Finances in Selected Metropolitan Areas and Large Counties. U.S. Department of Commerce, Bureau of the Census, Washington, DC 20233

"Annual report presenting detailed data on the finances of local government in major SMSA's and their county areas and in large county areas outside those SMSA's" (Congressional Information Service. 1977 American statistics index third annual supplement: abstracts. p. 273).

US-522

County Government Finances. U.S. Department of Commerce, Bureau of the Census, Washington, DC 20233

"Annual report presenting data on the finances of county government. Includes data on revenue by source, expenditure by function, and debt by population size groups, for counties with over 100,000 population and in more detail for counties with at least 500,000 population" (Congressional Information Service. 1977. American statistics index third annual supplement: abstracts. p 274).

US-523

Recreation Statistics. Department of Defense, Department of Army, Washington DC 20310

"A biennial report on recreation ;ivities and facilities at Army Corps f Engineers water resources development ;jects. Data are shown for each Corps iision, district, and individual pro- ec" (Congressional Information Service. 97. American statistics index third nal supplement: abstracts. p. 345).

US-524

ostruction Review. U.S. Department of omerce, Bureau of Domestic Commerce, shington, DC 20230

"Monthly report covering residential n other construction, including cost n valuation, number of units, permits, n contract awards for each type of con- tuction; and prices of materials and mloyment" (Congressional Information evice. 1976. American statistics in- e second annual supplement: abstracts. .173). The December issue is the an- ul statistical issue, having data for oger periods of time. Most of the data sby state with some information divided no standard metropolitan statistical ras.

US-525

vluation of Public Willingness to Pay sr Charges for Use of Outdoor Recrea- in Areas and Facilities. 1976. eartment of the Interior, Bureau of udoor Recreation, Washington, DC C40 (In 1978, the Bureau of Outdoor ereation became The Heritage, Conser- aion and Recreation Service)

"The Bureau of Outdoor Recreation au- trized this study to develop base data sto the current fee policies of govern- et agencies (measures of consistency in aagement), fee levels in comparable ulic and private areas (measures of cpetition), and public willingness to iectly pay for recreation services." is report was prepared in cooperation ih Economics Research Associates.

US-526

stern Economic Indicators. Federal eerve Bank of San Francisco, P.O. Box 72, San Francisco, CA 94120

"Bimonthly statistical series of economic indicators for the 12th Federal Reserve District States, (Alaska, Arizona, California, Hawaii, Nevada, Oregon, Utah and Washington) including comparisons with totals for the district as a whole and the U.S."

US-527

Annual Housing Survey. U.S. Department of Commerce, Bureau of the Census, Washington, DC 20233

"The annual housing survey collects more current data than the decennial Census of Housing. Data are based on probability samples of all housing units enumerated in the (latest) census, and of building permits issued since (the latest) census. Enumerators visit each sample unit and obtain information from the occupants, or, for vacant units from informed persons and by observation. Results are contained in several annual reports, some are published in both preliminary and revised formats" (Congressional Information Service. 1977. American statistics index third annual supplement: abstracts. p. 278). Each report contains an appendix on sources and the reliability of the estimates. The various reports are as follows:

General Housing Characteristics
This report presents number and characteristics of housing units and households, by region and location inside or outside SMSA's and central cities. Characteristics include total housing units and vacant units. A separate section deals with financial characteristics including income, unit value and monthly housing costs.

Indicators of Housing and Neighborhood Quality.
Indicators of housing and neighborhood quality are presented, by region and location inside or outside SMSAs and central cities. Characteristics include total housing units and vacant units. A separate section deals with financial characteristics

including income, unit value and monthly housing costs.

Indicators of Housing and Neighborhood Quality.
Indicators of housing and neighborhood quality are presented, by region and location inside or outside SMSAs and central cities. "Includes data on housing physical condition and occupancy, facilites available, equipment failures, and respondents' opinions of neighborhood conditions and services." (ASI, Fourth Annual Supplement)

Financial Characteristics of the Housing Inventory
"Annual report presenting cross-tabulation of housing unit value or rent and household income, by housing and household characteristics, for units inside or outside SMSAs and central cities of the U.S. and each region" (Congressional Information Service. 1977. American statistics index third annual supplement: abstracts. p. 279).

Housing Characteristics of Recent Movers
"Annual report presenting household characteristics of recent movers and characteristics of present and previous occupied units, by region and location inside or outside SMSAs and central cities" (Congressional Information Service. 1977. American statistics index third annual supplement: abstracts. p. 279).

Financial Characteristics by Indicators of Housing and Neighborhood Quality
"Annual report presenting data on financial characteristics of housing units and households. Data are cross-tabulated by indicators of housing and neighborhood quality, for units inside or outside SMSAs and central cities of the U.S. and each region" (Congressional Information Service. 1977. American statistics index third annual supplement: abstracts. p. 280).

Housing Characteristics for Selected Metropolitan Areas
"Annual series of reports, each for a specific SMSA, presenting characteristics of housing and households, indicators of housing and neighborhood quality, financial characteristics, and housing characteristics of recent movers" (Congressional Information Service. 1977. American statistics index third annual supplement: abstracts. p. 280).

Urban and Rural Housing Characteristics, U.S. and Regions
"Annual report presenting data cross-tabulated by urban-rural residence. Data cover characteristics of housing and households, indicators of housing and neighborhood quality, financial characteristics, and housing characteristics of recent movers" (Congressional Information Service. 1977. American statistics index third annual supplement: abstracts. p. 280).

US-528

Sales of Timber Appraised at $2,000 or More. U.S. Department of Agriculture, Forest Service, Regional offices and Washington office.

These computer print-outs, available from the Timber Management staffs in the Washington office of the Forest Service and in the respective regional offices (see App. A), report each sale of timber from National Forest lands. Data listed include the forest, pricing method, sale size, sale method, product, species, logging and manufacturing costs, selling value and the high bid rate.

US-529

Survey of Current Business. Department of Commerce, Bureau of Economic Analysis, Washington, DC 20230

A monthly report on economic con-[d]itions and business activity. Sections [in]clude general business indicators, [co]mmodity prices, construction and real [e]state, labor force, employment and [ea]rnings, lumber and products, and pulp [pa]er and paper products. A biennial [su]pplement, Business Statistics, con-[ta]ns identical data categories on a [hi]storical basis.

US-530

[Pu]blic Land Statistics. Department of [th]e Interior, Bureau of Land Management, [Wa]shington, DC 20240

"Annual report on public lands and [re]sources administered by the Bureau of [La]nd Management, shown by State. Covers [sa]es of land, timber, and minerals; use [fo]r grazing and recreation; conservation [an]d protection activities and financial [tra]nsactions" (Congressional Information [Ser]vice. 1977. American statistics [in]dex third annual supplement: abstracts. [p.] 545).

US-531

[Wa]ter Resources Data for (State). U.S. [De]partment of the Interior, U.S. Geologi-[ca]l Survey, 12201 Sunrise Valley Dr., [Re]ston, VA 22092

Annual reports issued for every [Sta]te consisting of "records of stage, [di]scharge, and water quality of streams; [sta]ge, contents, and water quality in [la]kes, and reservoirs; and water levels [in] wells." Data are presented in great [de]tail.

US-532

[Pu]lp, Paper and Board. U.S. Department [of] Commerce, Bureau of Domestic Commerce, [Wa]shington, DC 20230

"Quarterly report on the pulp, paper, [an]d board industry. Includes statistical [ser]ies on employment, prices, production, [sh]ipments, foreign trade, and raw materi-[al] consumption" (Congressional Informa-[ti]on Service. 1977. American statistics [in]dex second annual supplement: ab-[st]racts. p. 177).

US-533

Timber Supply and Use in the Haines-Skagway Area, Alaska. 1976. Vernon Labau and Keith Hutchinson. Resource Bulletin PNW-67. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, P.O. Box 3141, Portland, OR 97208

"Discusses the results of a 1965 forest inventory of 449,300 acres used in the Haines-Skagway area. Selected references are used to describe the economy of the area historically and currently. Interpretations and assessments of the timber resource in the continuing economy are made."

US-534

Timber Resources of Douglas Country, Oregon. 1976. C.D. Maclean. Resource Bulletin PNW-66. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, P.O. Box 3141, Portland, OR 97208

"This report summarizes a 1973 timber resource inventory of Douglas County, Oregon. Detailed tables of forest area, timber volume, growth, mortality, and cut are presented. A discussion of the present resource situation highlights the condition of cutover lands and the opportunities for silvicultural treatment."

US-535

Timber Resources and the Timber Economy of Okanogan County, Washington. 1975. Charles Bolsinger. Resource Bulletin PNW-58. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, P.O. Box 3141, Portland, OR 97208

"Timber resources and timber economy of Okanogan County, Washington, as of 1972 are summarized and projections are made to the year 2020."

US-536

Two Projections of Timber Supply in the Pacific Coast States. 1975. D.R. Gedney

et al. Resource Bulletin PNW-60. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, P.O. Box 3141, Portland, OR 97208

"Two projections of softwood timber supply for 1970-2020 for California, western Oregon, eastern Oregon, western Washington, eastern Washington, and coastal Alaska are presented. One projection shows how much timber will likely be available in the future if forest management continues at recent levels. The second projection shows the impact of one program of intensified management on future timber supplies for these States except coastal Alaska."

US-537

Timber Resource Statistics for the Fairbanks Block, Tanana Inventory Unit, Alaska, 1970. 1975. K.H. Hegg. Resource Bulletin PNW-59. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, P.O. Box 3141, Portland, OR 97208

"This resource bulletin reports on the findings of the first intensive forest inventory of a 3-million-acre unit near Fairbanks, Alaska. Included are comments on forest condition, defect, regeneration, fire history, and present use. Standard Forest Survey data are presented for commercial forest land and a special noncommercial forest land class."

US-538

Oregon Timber Harvest. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, P.O. Box 3141, Portland, OR 97208

Annual summary of Oregon timber harvest by ownership. Also includes stumpage prices on publicly owned land. This is issued in the Resource Bulletin series.

US-539

Washington Timber Harvest. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, P.O. Box 3141, Portland, OR 97208

Annual summary of Washington timber harvest by ownership. Also includes stumpage prices on publicly owned land. This is issued in the Resource Bulletin series.

US-540

Log Prices in Western Washington and Northwestern Oregon, 1963-73. 1974. T.C. Adams. Research Note PNW 235. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR 97208

"Average log prices are reported for seven principal timber species of western Washington and northwestern Oregon for the years 1963-1973."

US-541

Timber Resources of Northern Interior California, 1970. 1976. Charles Bolsinger. Resource Bulletin PNW-65. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR 97208

"Report on commercial forest land, timber volume, growth, and mortality in northern interior California (Lassen, Modoc, Siskiyou, Shasta and Trinity counties). Tables generally show data by ownership class, county, stand-size class, and species" (Congressional Information Service. 1977. American statistics index third annual supplement: abstracts. p. 51).

US-542

Price Impacts of Log Export Restrictions Under Alternative Assumptions. 1976. Richard Haynes. Research Paper PNW-212. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, P.O. Box 3141,

tland, OR 97208

"The impact on softwood lumber and mpage prices of a hypothetical ban of exports was computed for alternative umptions about the market for western twood lumber. The log export ban was ated as shifting the U.S. supply of tern softwood. Various assumptions e made about the direction, extent, timing of this shift. Other critical umptions included the values for the . and Canadian supply elasticities and U.S. demand elasticity. Price nges attributed to log export re- ictions were computed for each of the ious combinations of assumptions."

US-543

entory Report on Real Property Owned the U.S. Throughout the World. Gen- l Services Administration, Washing- , DC 20405

"Annual report on quantity, cost and of land, buildings, and other perma- t structures and facilities owned or d in trust by Federal Government, in tes, outlying areas, and foreign ntries" (Congressional Information vice. 1977. American statistics ex second annual supplement: ab- acts. p. 794).

US-544

ber Resources of Mendocino and Sonoma nties, California. 1972. Daniel ald. Resource Bulletin PNW-40. U.S. artment of Agriculture, Forest vice, Pacific Northwest Forest and ge Experiment Station, P.O. Box 3141, tland, OR 97208

"This report presents the findings of first complete inventory of the tim- resources of Mendocino and Sonoma nties, California. Accompanying the les of detailed forest area, volume, wth, and mortality statistics is an lysis of the present timber resource, h emphasis on conditions that affect sent and future timber production."

US-545

State and County Employment and Unemployment. U.S. Department of Labor Bureau of Labor Statistics, Washington, DC 20210

"This publication includes monthly estimates of the labor force, employment and unemployment for States and counties. These estimates have been furnished to the Economic Development Administration of the U.S. Department of Commerce for use in the administration of the Public Works and Economic Development Act of 1965 as amended, and the Public Works Employment Act of 1976. Because of the small size of many of the areas, as well as limitations of the data inputs, these estimates are subject to considerable statistical error."

US-546

Monthly Labor Review. U.S. Department of Labor, Bureau of Labor Statistics, Washington, DC 20210

Monthly report with information and statistics on current labor developments. There are monthly feature articles as well as statistics on employment, wages and prices.

US-547

Handbook of Labor Statistics. U.S. Department of Labor, Bureau of Labor Statistics, Washington, DC 20210

"Annual compilation of statistical data on labor conditions and characteristics for the U.S. (This) volume is compiled from major Bureau of Labor Statistics series and related series from other governmental agencies" (Congressional Information Service. 1977. American statistics index third annual supplement: abstracts. p. 595). Sections include labor force, employment, unemployment, wages and prices.

US-548

Employment and Earnings. U.S. Department of Labor, Bureau of Labor Statistics, Washington, DC 20210

"Monthly report presenting current

statistics on U.S. employment status, unemployment, hours and earnings, labor turnover, and unemployment insurance" (Congressional Information Service. 1977. American statistics index third annual supplement: abstracts. p. 598).

US-549

Employment and Earnings, States and Areas. U.S. Department of Labor, Bureau of Labor Statistics, Washington, DC 20210

"Comprehensive annual collection of statistics on average annual employment, hours, and earnings. Data are shown by industry for 50 states, D.C., and major areas" (Congressional Information Service. 1977. American statistics index third annual supplement: abstracts. p. 603).

US-550

1972 OBERS Projections, Regional Economic Activity in the U.S.: Series E Population. 1974. U.S. Water Resources Council, 2120 L St. N.W., Washington, DC 20037

"Report in seven volumes presenting economic projections through 2020 to provide basic data to public agencies engaged in comprehensive planning for use, management, and development of U.S. water and related land resources. Reports present projections of population, personal income, and personal employment earnings and output covering 1980, 1985, 1990, 2000, and 2020 for: the U.S. as a whole; for 1973 Bureau of Economic Analysis delineated functional economic areas by 37 industry groups; for 20 water resources regions and 205 water resources subareas by 28 industry groups; and for the 50 states and D.C.

Contents of each report are described separately below. In addition, 1 or more of the 5 basic tables, listed below, appear in each report with data for the U.S. and for the areas covered by the particular report. Additional data on personal income and agricultural production are available from Bureau of Economic Analysis and Economic Research Service (now the Economics, Statistics and Cooperatives Service) rapid retrieval systems in computer printout form.

Basic Tables:

1. Populations, employment, persona[l] income, and earnings by industry historical and projected, select[ed] years, 1950-2020.

2. Agricultural and forestry production by commodity groups, histor[i]cal and projected, selected year[s] 1954-2020.

3. Agricultural and forestry production by commodity groups, histor[i]cal and projected, selected year[s] 1954-2020.

4. Value of agricultural production by commodity groups, historical and projected, selected years, 1954-2020.

5. Use of land resources, selected historical and projected years, 1954-2020.

Reports (include):

Vol. 1: Concepts, Methodology, and Summary Data
5 basic tables (listed above) with data for U.S.; and 28 summary tables, showing projectio[ns] for selected years 1929-2020, [by] Bureau of Economic Analysis ec[o]nomic area, by water resources region and subarea, by SMSA's and non-SMSA areas, and by State, of: population, persona[l] income, and per capita persona[l] income; crop and livestock production, valued at 1967 prices[;] and commercial forest area and roundwood production.

Vol. 2: Economic Areas
Presents basic tables 1 and 2 (listed above) for U.S.; and ta[-]bles 1, repeated for each of t[he] 173 Bureau of Economic Analysi[s] areas.

Vol. 3: Water Resources Regions and Subareas
Presents basic tables 1-5 (listed above) for U.S.; tables 1, 3, and 4, repeated for each water resources region; and table 1, repeated for each water resources subarea.

Vol. 4: States
Presents basic tables 1-5 (listed above) for U.S.; tables 1, 3, and 4 repeated for each of the 50 states.

Vol. 5: Standard Metropolitan Statistical Areas
Presents basic table 1 (listed above) for U.S.; and table 1, repeated for each of the 253 SMSA's.

Vol. 6: Non-SMSA Portions of Economic Areas
Present basic table 1 (listed above) for U.S.; and table 1, repeated for each non-SMSA portion of the 173 Bureau of Economic Analysis areas.

Vol. 7: Non-SMSA Portions of Water Resources Subareas
Presents basic table 1 (listed above) for U.S.; and table 1, repeated for each non-SMSA water resources subarea."

(Congressional Information Service. 1975. American statistics index first annual supplement: abstracts. p. 751).

US-551

1972 OBERS Projections, Series E, Projections and Historical Data: Population, Personal Income and Earnings, Aggregated Subareas. 1974. U.S. Water Resources Council, 2120 L St. N.W., Washington, DC 20037.

"Report presenting historical data (1950-71) and projections (1975-2000) of population, employment, personal income, and earnings, for the U.S., 20 (of 21) water resource regions (including totals only for Alaska and Hawaii; excluding the Caribbean), and 99 aggregated subareas of the contiguous U.S. The aggregated data in this report (except the 1975 projections) were published in disaggregated format in 1972 OBERS Projections, Series E Population" (Congressional Information Service. 1977. American statistics index third annual supplement: abstracts. p. 965) (see US-550).

US-552

1972 OBERS Projections, Regional Economic Activity in the U.S.: Series E Population Supplement, Agricultural Projections, Vols. 1, 3 and 4. 1975. U.S. Water Resources Council, 2120 L Street N.W., Washington, DC 20037.

"Report presenting baseline projections of agricultural production, forestry production and farm land use, through the year 2020. Projections are revised from those which appeared in the 7-volume 1972 OBERS Projections, Series E Population" (Congressional Information Service. 1976. American statistics index second annual supplement: abstracts. p. 895) (see US-550).

US-553

1972 OBERS Projections, Series E, Incremental Projections and Ratios of Future (1975) Populations, Personal Income and Earnings Aggregated Subareas. 1975 U.S. Water Resources Council, 2120 L Street N.W., Washington, DC 20037.

"Report presenting ratios of projected 1985 and 2020 population to projected 1975 population, employment, personal income, and earnings (by major industry division and group), for 99 subareas comprising the 18 water resource regions of the contiguous U.S. Based on projections appearing in 1972 OBERS Series E Projections and Historical Data, Populations, Personal Income and Earnings, Aggregated Subareas" (Congressional Information Service. 1977. American statistics index third annual supplement: abstracts. p. 965) (see US-551).

Notes about OBERS:

These reports are done in cooper-

ation w..h U.S. Department of Commerce, Bureau of Economic Analysis and U.S. Department of Agriculture, Economics, Statistics, and Cooperatives Service (formerly the Economic Research Service). Their main purpose is to provide data to public agencies involved in land and water resources planning and management. At this writing plans are being developed to revise the projections on a regular basis. For further information contact the U.S. Water Resources Council.

US-554

National Economic Trends. Federal Reserve Bank of St. Louis, 411 Locust, St. Louis, MO 63102

"Monthly compilation of charts and tables showing monthly or quarterly economic indicators for the U.S. as a whole" (Congressional Information Service. 1977. American statistics index third annual supplement: abstracts. p. 849). Data includes employment and personal income.

US-555

Forest Area And Timber Volume Statistics For Western South Dakota, 1974. Gary Clendenen, Shirley Water, and J. David Born. Research Note INT-208. 1976. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, 507 25th St., Ogden, UT 84401

"Presents land area classifications by Forest and Range Resources Evaluation standards and timber volume data by species, forest type, stand-size class, and ownership."

US-556

The Rocky Mountain Timber Situation, 1970. 1974. Alan Green and T. Setzer. Resource Bulletin INT-10. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, 507 25th St., Ogden, UT 84401

"Presents highlights of the 1970 forest situation in the Rocky Mountain States. Describes the forest resource and the timber supply outlook. Includes statistical tables: areas by land classes; ownership; growing stock volumes; net annual growth; mortality; roundwood products output; and logging residues" (states include Arizona, Colorado, Idaho, Montana, Nevada, New Mexico South Dakota, Utah, Wyoming). At this writing, plans are to update the timber inventory in this area of the country on a 9-year cycle.

US-557

Industry-Specific Gross Output for Bureau of Economic Analysis Economic Areas. 1977. U.S. Department of Commerce, Bureau of Economic Analysis, Washington, DC 20230

(This publication may also be cited as Guideline 5, Regional Multipliers, U.S. Water Resources Council).

This publication contains input-output type multipliers for 56 industrial sectors for each of 173 Bureau of Economic Analysis economic areas. These multipliers permit the assessment of economic impact of public and private investment projects on the economic areas. The industrial sectors include, among others, various forestry, lumber and mining categories.

US-558

Weekly Business Statistics. U.S. Department of Commerce, Bureau of Economic Analysis, Washington, DC 20230

Updates selected data that are published monthly in the Survey of Current Business (see US-529).

US-559

Local Area Personal Income, U.S. Department of Commerce, Bureau of Economic Analysis, Washington, DC 20230

"Annual (multi-volume) report presenting estimates of total and per capita personal income by place of residence, personal income by source, and labor and proprietors' income by industry division

d place of work. Data are shown for ates, Bureau of Economic Analysis onomic Areas, and counties" (Congres-sonal Information Service. 1978. erican statistics index fourth annual pplement: abstracts. p. 293).

US-560

ea Economic Projections, 1990. 1974. S. Department of Commerce, Bureau of onomic Analysis, Washington, DC 20230

"Report presenting projections of rsonal income, earnings, employment, d population in 1980 and 1990, for reau of Economic Analysis Economic eas, SMSA's and States" (Congressional formation Service. 1975. American atistics index first annual supplement: stracts. p. 262).

US-561

tional Park Statistical Abstract. U.S. partment of the Interior, National Park rvice, Statistical Section, Denver rvice Center, P.O. Box 25287, Denver, 80225

Annual compilation of visitor data to eas administered by the National Park rvice. Prior to 1977, this data was ntained in Public Use of the National rk System and Overnight Stays.

US-562

blic Use of the National Parks. U.S. partment of the Interior, National Park rvice, Washington, DC 20240

This monthly report summarizes public e of national parks. Data for each rk are presented and include month of verage and year to date. These reports e not as reliable as the National Park atistical Abstract (see also US-801).

te: At this writing the National Park rvice is developing a system for eater collection and availability of ta, especially socioeconomic data. recasts of use data will be made when e system is in full operation in areas ministered by the National Park rvice.

US-563

Handbook of Agricultural Charts. U.S. Department of Agriculture, Washington, DC 20250

Annual publication consisting of charts on agricultural topics, including information on livestock production and prices.

US-564

Federal and Indian Lands: Oil and Gas Production, Royalty Income and Related Statistics. U.S. Department of the Interior, Geological Survey, 12201 Sunrise Valley Drive, Reston, VA 22092

"Annual statistical report on oil and gas related mineral production and revenues of Federal, Indian, Naval Petroleum Reserve, and Outer Continental Shelf lands under lease, license, and prospecting permits in past year and selected prior years" (Congressional Information Service. 1977. American statistics index third annual supplement: abstracts. p. 535).

US-565

Federal and Indian Lands: Coal, Phosphate, Potash, Sodium, and Other Mineral Production, Royalty Income, and Related Statistics. U.S. Department of the Interior, Geological Survey, 12201 Sunrise Valley Drive, Reston, VA 22092

"Annual statistical report on the production, value, and royalties of coal, phosphate, and other minerals on Federal, Indian, Naval Petroleum Reserve, and Outer Continental Shelf lands under lease, license, and prospecting permits in past year and selected previous years" (Congressional Information Service. 1977. American statistics index third annual supplement: abstracts. p. 535).

US-566

Livestock and Meat Statistics. U.S. Department of Agriculture, Economics, Statistics, and Cooperatives Service, Washington, DC 20250

Annual compilation of data on livestock and meat production, marketing, prices and trade. Most of the tables in this report are published regularly on a weekly or monthly basis in The Livestock Meat and Wool Market News (see US-568).

US-567

Livestock and Meat Situation. U.S. Department of Agriculture, Economics, Statistics and Cooperatives Service, Washington, DC 20250

"Report (six issues with six supplements yearly) compiling information and statistics on current production and marketing of livestock and meat" (Congressional Information Service. 1977. American statistics index third annual supplement: abstracts. p. 97).

US-568

Livestock, Meat, and Wool Market News: Weekly Summary and Statistics. U.S. Department of Agriculture, Agricultural Marketing Service, Washington, DC 20250

"Weekly news summary and statistics for livestock, meat, and wool markets for preceding week, with some earlier comparative data" (Congressional Information Service. 1977. American statistics index third annual supplement: abstracts. p. 64).

US-569

Recreation Access Study, Appendix 1, Inventory of Regionally Significant Federal and State Recreation Resources. 1975. Michael Schneider. U.S. Department of Transportation, 400 Seventh St. S.W., Washington, DC 20590

"This report is an Appendix to the Recreation Access Study Summary Report and contains the complete listing of some 1800 recreational resources reviewed as part of the study." The research effort focused on resources which were sufficiently significant as to attract substantial visitation--that is, resources which, because of their facility activity mix, proximity to urban areas, size and general configuration are significant elements in the recreation resource system of a given metropolitan region. The inventory is thus limited to resources with a reported 1973 visitation of 100,000 or more. Federal and state agencies were asked to supply the name, size (in acres), location (i.e., state), annual visitation, and facilities/activities available for all resources under their jurisdiction. The information was coded for computer storage and retrieval according to resource type and facilities available." Appendix 2 of this study is entitled Case Studies and Appendix 3 User Access Survey Tabulations with Boston and Atlanta used as examples. This study was conducted by VTN Consolidated, Inc., Irvine, California, under a cooperative agreement.

US-570

Wholesale Price Index. U.S. Department of Labor, Bureau of Labor Statistics, Washington, DC 20210

This monthly press release has tabulations covering price movements over the month for commodity groups and subgroups. Major commodity groups include lumber and wood products and pulp paper and allied products. Report is issued approximately one to two weeks after end of month covered.

US-571

Wholesale Prices and Price Indexes. U.S. Department of Labor, Bureau of Labor Statistics, Washington, DC 20210

"Monthly report on wholesale prices and price indexes for major commodity groups, subgroups, special groups, and individual items" (Congressional Information Service. 1977. American statistics index third annual supplement: abstracts. p. 608). Major commodity groups include lumber and wood products and pulp, paper and allied products. Report is issued approximately two months after month of coverage.

US-572

Wholesale Prices and Price Indexes, Supplement (Year), Data for (Past Year).

. Department of Labor, Bureau of Labor tistics, Washington, DC 20210

This publication is an annual supment to the monthly Wholesale Prices Price Indexes (see US-571).

US-573

ual Wildlife Report. U.S. Department Agriculture, Forest Service, P.O. Box 7, Washington, DC 20013

Annual compilation of wildlife population estimates, hunter harvest, habitat complishments, and sportsman use on nanal forests and national grasslands.

US-574

ters and Hunting: Management Implications of Research. 1976. John Hendee Dale Potter. General Technical Ret SE-9. U.S. Department of Agricule, Forest Service, Southeastern For- Experiment Station, Post Office lg., Box 2570, Asheville, NC 28802

(General Technical Report SE-9 is led Proceedings of the Southern States reation Research Applications Workp, Asheville, North Carolina, Septem 15-18, 1975, and contains numerous dies, including the one mentioned e.)

"Data are summarized from 33 studies taining to hunting participation--ter characteristics including age, cation, occupation, income, residence; ter motives; membership in sportsmen anizations and reading of sporting azines; antihunting sentiment; and consumptive wildlife use."

US-575

deral Recreation Fees: Including the ual Federal Recreation Area Visitation a. U.S. Department of the Interior, itage, Conservation and Recreation vice, Washington, DC 20240

(ior to 1978 this agency was the Bureau Outdoor Recreation).

This annual report contains data on recreation fees collected by Federal agencies and use of federally managed recreation units.

US-576

State Hunting and Fishing License Sales. U.S. Department of the Interior, Fish and Wildlife Service, Washington, DC 20242

Annual Department of the Interior news release on state hunting and fishing license sales, including tables on hunting and fishing by state.

US-577

Mourning Dove Status Report. U.S. Department of the Interior, Fish and Wildlife Service, Washington, DC 20242

"Annual report on status of the breeding population of mourning doves, based on call-count survey conducted annually since 1953, which records the number of birds heard on established routes" (Congressional Information Service. 1978. American statistics index fourth annual supplement: abstracts. p. 493).

US-578

Outlook For Housing By Type of Unit and Region: 1978 to 2020. 1977. Thomas Marcin. Research Paper FPL-304. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, P.O. Box 5130, Madison, WI 53705

"Updated projections are given for U.S. housing demand for use in planning by public agencies and private businesses." This report is an update of the 1972 publication Projections of Demand for Housing by Type of Unit and Region (U.S. Department of Agriculture, Forest Service, Agriculture Handbook 428).

US-579

Timber Resources of Southwest Oregon. 1977. Patricia Bassett. Resource Bulletin PNW-72. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, P.O. Box 3141, Portland, OR 97208

"This report presents statistics from a 1973 inventory of timber resources of Douglas County and from a 1974 inventory of timber resources of Coos, Curry, Jackson, and Josephine Counties, Oregon. Tables presented are of forest area and of timber volume, growth and mortality."

US-580

Minerals Yearbook. U.S. Department of Interior, Bureau of Mines, 2401 E St. N.W., Washington, DC 20241

Annual compilation of data for metals, minerals, and mineral fuels produced or used by the U.S. mineral industry. Generally issued as a three-volume report, "Volume I reviews individual metal and nonmetal mineral commodities, Volume II contains data by state, while Volume III, is a world mineral industry review." Individual chapters are published in advance of the complete three volumes.

US-581

Mineral Commodity Summaries. U.S. Department of Interior, Bureau of Mines, 2401 E St. N.W., Washington, DC 20241

Annual report presenting mineral industry data from the past year. This report is the earliest Government publication to furnish coordinated estimates from the past year.

US-582

Mineral Commodity Profiles. U.S. Department of the Interior, Bureau of Mines, 2401 E St. N.W., Washington, DC 20241

This series of reports updates selected chapters of Mineral Facts and Problems (US-583). These reports cover individual commodities.

US-583

Mineral Facts and Problems. U.S. Department of the Interior, Bureau of Mines, 2401 E St. N.W., Washington, DC 20241

Publication, updated every fifth year, reviewing mineral commodities, including U.S. and world industry structure, supply and demand, trade, and selected trends and future outlooks. Individual chapter preprints are also published.

US-584

Minerals and Materials: A Monthly Survey. U.S. Department of the Interior, Bureau of Mines, 2401 E St. N.W., Washington, D 20241

"Monthly report on mineral commodities and fossil fuels, covering production/consumption, foreign trade, inventories, and representative prices" (Congressional Information Service. 1977. American statistics index third annual supplement: abstracts. p. 509).

US-585

Minerals in the U.S. Economy: Ten-Year Supply-Demand Profiles for Mineral and Fuel Commodities. U.S. Department of the Interior, Bureau of Mines, 2401 E St. N.W., Washington, DC 20241

This publication is a compendium of supply and demand statistics for mineral and fuel commodities.

US-586

Water and Land Resource Accomplishments. U.S. Department of Interior, Bureau of Reclamation, Washington, DC 20240.

This annual report discusses the Federal reclamation land and water resource development and management program in 17 western states. The report is issued in four volumes. The Summary Volume and Statistical Appendix 1 have information on recreation areas and sportsmen take on reclamation projects. Computer printouts which provide more detailed unpublished data are also available on request.

US-587

Census of Transportation: National Trave Survey. U.S. Department of Commerce, Bureau of the Census, Washington, DC 20233

Part of the quinquennial Census of ansportation, taken for years ending in " and "7", which also includes Truck ventory and Use Survey and Commodity ansportatiohn Survey. This report is extensive survey of travel activity in e U.S. during the census year. In er years the U.S. Travel Data Center nducts a similar study (see PR-524 and -525). In addition to the published ports, public use computer tapes are so available (see US-901).

US-588

imated Use of Water in the United ates in (year). U.S. Department of erior, Geological Survey, 1200 South ls St., Arlington, VA 22202.

Report issued every fifth year, pre-nting data on water withdrawn for use the United States by five major cate-ies of use: public supply, rural, ir-gation, self-supplied industrial, and droelectric power.

US-589

Summary of Knowledge of the Central d Northern California Coastal Zone and shore Areas, Vol. III, Socioeconomic nditions. 1977. U.S. Department of erior, Bureau of Land Management, shington, DC 20240 (Available through S, PB-274 215 and PB-274 216)

Volume III of this report was issued two books. Book 1 reviews industrial, mercial and military activity, the troleum industry, transportation sys-s, demography and socioeconomic con-iderations, and land and water use. ok 2 contains information on pollution urces, historical and archaeological sources, and recreational site vulner-lity. Volume I of this study summa-es physical conditions, Volume II re-ws biological conditions and Volume is a bibliography. This study was pared by Winzler and Kelly Engineers, eka, California.

US-590

er Supply Outlook for the Western ted States. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, W22, Silver Spring, MD 20910

"Report published monthly January-May providing forecasts of seasonal snowmelt and runoff for rivers where snow is the principle source of stream flow. Covers stations for 11 Western States" (Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington and Wyoming) (Congressional Information Service. 1976. American statistics index second annual supplement: abstracts. p. 183).

US-591

California Forest Industry, Wood Consumption and Characteristics. 1974. J.O. Howard. Resource Bulletin PNW-52. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, P.O. Box 3141, Portland, OR 97208

Survey done approximately every five years of the forest products industry of California. "Tabular presentation includes characteristics of the industry log consumption statistics, and disposition of mill residues." The last survey as of this writing was for 1972 and was a 100-percent canvass of the industry.

US-592

Regional Work Force Characteristics and Migration Data: A Handbook on the Social Security Continuous Work History Sample and Its Applications. 1976. U.S. Department of Commerce, Bureau of Economic Analysis, Washington, DC 20230

A comprehensive study of the uses and availability of state and local area work force characteristics and migration data. Documents for the first time the Continuous Work History Sample (CWHS) and discusses its applications, comparability with other series, and its limitations. Includes annotated bibliography of studies using CWHS data and an appendix detailing data sources and procedures. "The Social Security Administration's CWHS is a uniquely detailed source of information on work force characteris-

tics and the components of work force change for states and substate areas for intercensal years. These data can help planners monitor and evaluate the effects on area workers of economic events and policies" (see also US-902).

US-593

Recreational Boating in the Continental United States in (Year): The Nationwide Boating Survey. U.S. Department of Transportation, Coast Guard, Office of Boating Safety, Washington, DC 20590

(Available through NTIS)

Report issued about every three years on recreational boat ownership and use. Report also includes data on boating household and operator characteristics.

US-594

"Input-Output Data," U.S. Department of Commerce, Bureau of Economic Analysis, Washington, DC 20230

Numerous publications and computer tapes with input-output data are available. The input-output structure of the American economy is reviewed and analyzed in detail approximately every fifth year. This process generally takes several years, with revisions and updates made as necessary in ensuing years. Over the years titles of publications and computer tapes with input-output data have changed; however titles are expected to be the same in the future. Bureau of Economic Analysis publications generally are available through NTIS. At this writing some of the available publications are:

1) Input-Output Structure of the U.S. Economy: 1967

"The input-output tables depict the interactions of 367 industries. They show, for each industry, the amount of its output that goes to each other industry as raw materials or semifinished products and the amount of output that goes to final market of the economy. The tables also show each industry' consumption of products of othe industries and its contribution to gross national product as measured by value added. The tables permit the tracing of th industrial effects, direct and indirect, of changes in consume demand, in demand for investmen goods, in exports, and in government purchases" (U.S. Department of Commerce, Bureau of Economic Analysis. 1977. Publications and computer tapes of the Bureau of Economic Analysis p. 6.). Issued in three volumes:

Vol. 1 Transactions Data for Detailed Industries
Vol. 2 Direct Requirements for Detailed Industries
Vol. 3 Total Requirements for Detailed Industries

2) Staff Paper 27: Summary Input-Output Tables of the U.S. Economy: 1968, 1969, 1970. Paula Young and Philip Ritz.

"This report presents input-output (I-0) tables of the U.S. economy for 1968, 1969, a 1970, obtained by updating BEA benchmark I-0 table for 1967 a the 85-industry level. It als includes a comparison of actua industry output for 1968, 1969 and 1970 with output estimated using the 1967 I-0 coefficient and the estimates of final demand prepared in this study fo 1968, 1967, and 1970."

3) Staff Paper 28: Input-Output Table of the U.S. Economy: 1971. Paula Young and Philip Ritz.

"Provides input-output tables for 1971 at the 85-industry level, based on application of update procedures to the 1967 benchmark input-outpu table, revised to reflect the January, 1976, revision in the national income and product accounts."

4) Staff Paper 29: Revised Input-Output Tables for the United States: 1967. Albert Walderhaug.

Revised input-output tables are provided for 1967 at the 85-industry level of detail.

At this writing some of the available computer tapes are:

1) Interindustry Transactions and Margins for the Revised 1967 Input-Output Table

"Interindustry transactions (sales and purchases and margins (trade and transportation costs) for the revised 1967 input-output table. Data are available at the 85, 367, and 484-industry levels. The 85 and 367-industry level tapes include transactions and margins, direct requirements coefficients, and total requirement coefficients. The 484-industry level tape contains only the transactions and margins" (U.S. Department of Commerce, Bureau of Economic Analysis. 1977. Publications and computer tapes of the Bureau of Economic Analysis. p. 7).

2) 85-Industry Transactions for the 1971 Input-Output Tables

"Interindustry transactions, directly allocated output, transferred output direct requirements, total requirements" (U.S. Department of Commerce, Bureau of Economic Analysis. 1977. Publications and computer tapes of the Bureau of Economic Analysis. p. 7).

US-595

Report of the Forest Service. U.S. Department of Agriculture, Forest Service, P.O. Box 2417, Washington, DC 20013

Annual report, issued on a fiscal year basis, on the progress of Forest Service programs. Data on major resource activities are summarized. This report was first issued in 1978 and replaces Report of the Chief, Forest Service (US-512).

US-596

Timber Resources of the Sacramento Area, California, 1972. 1978. Brian Wall. Resource Bulletin PNW-73. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, P.O. Box 3141, Portland, OR 97208

"This report summarizes the 1972 timber resource inventory of the Sacramento area, California. Included are detailed tables of forest area, timber volume, growth, mortality, and timber cut and a discussion of the current timber resource and timber industry situation."

US-597

Mineral Industry Surveys. U.S. Department of the Interior, Bureau of Mines, 2401 E St. N.W., Washington, DC 20241

"Processed reports that contain statistical and economic data on various mineral commodities. These reports are issued at regular intervals (weekly, monthly, quarterly, semiannually, or annually) so that information on mineral commodities may be made available quickly and in a convenient form. Most of the data contained in these reports appear in permanent form in the Minerals Yearbook" (US-580) (U.S. Department of the Interior, Bureau of Mines. 1977. List of Bureau of Mines publications and articles, 1976). The types of data vary in different reports, as the most important data are included for each mineral commodity.

US-598

Mineral Trade Notes. U.S. Department of Interior, Bureau of Mines, 2401 E St. N.W., Washington, DC 20241

Monthly report reviewing the international mineral situation. Data includes production and trade figures. Contents

vary from month to month.

US-599

Western South Dakota Timber Production and Mill Residues. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, 507 25th St., Ogden, UT 84401

Forest Service Research Note issued approximately every fifth year summarizing timber harvest by species and product in western South Dakota. At this writing the last Research Note was published in 1977 (Research Note INT-233), with data from 1974.

US-600

Utah Timber Production and Mill Residues. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, 507 25th St., Ogden, UT 84401

Forest Service Research Note issued approximately every fifth year summarizing timber harvest by species and product in Utah. At this writing the last Research Note was published in 1977 (Research Note INT-234), with data from 1974.

US-601

Arizona Timber Production and Mill Residues. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, 507 25th St., Ogden UT 84401

Forest Service Research Note issued approximately every fifth year summarizing timber harvest by species and product in Arizona. At this writing the last Research Note was published in 1977 (Research Note INT-230), with data from 1974.

US-602

New Mexico Timber Production and Mill Residues. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, 507 25th St., Ogden, UT 84401

Forest Service Research Note issued approximately every fifth year summarizing timber harvest by species and product in New Mexico. At this writing the last Research Note was published in 1977 (Research Note INT-231), with data from 1974.

US-603

Colorado Timber Production and Mill Residues. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, 507 25th St., Ogden, UT 84401

Forest Service Research Note issued approximately every fifth year summarizing timber harvest by species and product in New Mexico. At this writing the last Research Note was published in 1977 (Research Note INT-232), with data from 1974.

US-604

Index to Selected 1970 Census Reports. U.S. Department of Commerce, Bureau of the Census, Washington, DC 20233

"This is a reference guide designed to facilitate easier use of reports from the 1970 Census of Population and Housing. These 1970 Census reports provide data for States, standard metropolitan statistical areas, cities, counties, subdivisions, census tracts and other small areas." See also Index to 1970 Census Summary Tapes (US-906).

US-605

Historical Forestry Statistics of the United States. 1958. U.S. Department of Agriculture, Forest Service, P.O. Box 2417, Washington, DC 20013

"The objective of this report is to bring together in convenient reference form those historical forestry and forest products statistics which seem to be of the widest general interest to workers in conservation and forestry." This publication has been continued in part by The Demand and Price Situation For Forest Products (see US-504).

US-606

Historical Statistics of the United States, Colonial Times to (Year). U.S. Department of Commerce, Bureau of the Census, Washington, DC 20233

A periodical publication providing a wide range of statistical data quantifying various aspects of the economic and social development of the United States. This publication is "designed to bring together historical series of wide general interest and to inform the user where additional data can be found." Data categories include forestry, population, labor, minerals and construction and housing.

US-607

Water Supply Outlook for Western United States, Including Columbia River Drainage in Canada. U.S. Department of Agriculture, Soil Conservation Service, 511 N.W. Broadway, Portland, OR 97209

"Report published monthly February to June, on the water supply outlook for eleven western states (Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, Wyoming) and Alaska, including selected streamflow forecasts, summary of snow accumulations, and storage in larger reservoirs" (Congressional Information Service. 1978. American statistics index fourth annual supplement: abstracts. p. 48).

US-608

Fall Water Supply Summary. U.S. Department of Agriculture, Soil Conservation Service, 511 N.W. Broadway, Portland, OR 97209

"Annual summary of the water supply for eleven western states (Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, Wyoming). Narrative reviews the past snowmelt season, current soil moisture, carryover reservoir storage, and the outlook for the West and each state (with accompanying tables)" (Congressional Information Service. 1978. American statistics index fourth annual supplement: abstracts. p. 45).

US-609

Water Supply Outlook for Utah. U.S. Department of Agriculture, Soil Conservation Service, 4012 Federal Bldg., Salt Lake City, UT 84138

"Annual report on Utah's water supply outlook for (the) water year. Data on streamflow, reservoir storage, and precipitation were provided by cooperating Federal, state, municipal, public and private agencies." (Congressional Information Service. 1978. American statistics index fourth supplement: abstracts. p. 49).

US-610

Water Supply Outlook for Montana. U.S. Department of Agriculture, Soil Conservation Service, P.O. Box 970, Bozeman, MT 59715

Annual report on water supply and outlook for Montana with snow cover comparisons and reservoir capacity and storage being among the types of data tabulated.

US-611

Fall Water Supply Summary for Nevada. U.S. Department of Agriculture, Soil Conservation Service, P.O. Box 4850, Reno, NV 89505

"Annual report on water supply and outlook for Nevada. Data on stream flow, reservoir storage, and precipitation were provided by cooperating federal, state, municipal and private agencies" (Congressional Information Service. 1978. American statistics index fourth annual supplement: abstracts. p. 49).

US-612

Water Supply Summary and Outlook for Oregon. U.S. Department of Agriculture, Soil Conservation Service, 1220 S.W. Third Ave., Portland, OR 97204

Annual report on water supply and

outlook for Oregon, containing data on stream flow and reservoir capacity and storage.

US-613

Water Supply Outlook and Federal-State-Private Cooperative Snow Surveys. U.S. Department of Agriculture, Soil Conservation Service, West Technical Service Center, 511 N.W. Broadway, Portland, OR 97209

"Series of ten western state periodic reports (Alaska, Arizona, Colorado and New Mexico, Idaho, Montana, Nevada, Oregon, Utah, Washington, Wyoming), most published monthly in winter and spring, with basic data on snow depth, soil moisture, reservoir storage, and other matters relating to the water supply outlook. Reports are compiled by state offices of the Soil Conservation Service from data gathered by federal, state, and private organizations cooperating on snow surveys. State reports are not identical; nor does each issue of a state report include all the same data items." (Congressional Information Service. 1978. American statistics index fourth annual supplement: abstracts. p. 49). These reports may be obtained from the address listed above, or from state offices of the Soil Conservation Service at address listed in Appendix II. At this writing, state reports are issued as follows:

Alaska:	monthly, February to June
Arizona:	monthly, February to April
Colorado:	monthly, February to June
Idaho:	monthly, January to June
Montana:	monthly, January to June and May 15
Nevada:	monthly, January to May
New Mexico:	monthly, February to June
Oregon:	monthly, January to June
Utah:	monthly, January to June
Washington:	monthly, February to June
Wyoming:	monthly, February to June

Water Supply Outlook for the Western United States Including Columbia River Drainage in Canada (US-607) summarizes these reports.

US-614

Census of Mineral Industries. U.S. Department of Commerce, Bureau of the Census, Washington, DC 20233

Census, taken in years ending in "2" and "7", providing data on the number of establishments, and their employment and payrolls, assets and expenditures, consumption and costs, and shipments and receipts. Data are shown by industry, and for states and regions. Results of the Census are published first as advanc and preliminary industry reports. These are superseded by final reports" (Congressional Information Service. 1977. American statistics index third annual supplement: abstracts. p. 295). Census results are also available on computer tape.

US-615

Social Indicators. U.S. Department of Commerce, Bureau of the Census, Washington, DC 20233

Statistics on social conditions and trends in the United States and selecte other countries are available in this publication. Included in this publication are sections on population, housing, work, income and recreation. As o this writing, this report has been issu for 1973 and 1976.

US-616

Chartbook on Prices, Wages, and Productivity. U.S. Department of Labor, Bure of Labor Statistics, 441 G. St. N.W., Washington, DC 20212

"This chartbook (published monthly) presents a comprehensive picture of cur rent changes in prices, wages, costs, profits and productivity in the U.S. economy, in their historical setting. Most of the charts show seasonally adjusted or annual rates of change."

US-617

rgy Information Report to Congress. ;. Department of Energy, Energy Infor- :ion Administration, Washington, DC 161

This is a "quarterly report to Con- ss on production, imports/exports, l inventories of domestic coal, natural , crude and refined petroleum, nuclear rgy, and electric power. Through the ond quarter 1977 issue, (this) report issued by the now-abolished Federal rgy Administration" (Congressional ormation Service. 1978. American tistics index supplement No. 3: ab- acts. p. 32).

US-618

erals in the Economy of (state). U.S. artment of Interior, Bureau of Mines, l E St. N.W., Washington, DC 20241

In 1978 the Bureau of Mines inaugu- ed a new series of annual state miner- profiles, that are produced in cooper- on with state geologists or equivalent icials. They present the latest data mineral resources and production and federal and state government programs ecting mineral resource development each state.

US-619

ld Demand for Raw Materials in 1985 2000. 1977. Wilfred Malenbaum. ional Science Foundation, Applied ence and Research Applications, 1800 t. N.W., Washington, DC 20550

ailable through NTIS PB 277 707. s study was conducted by the nomics Department, University of nsylvania, Philadelphia, PA 19174)

"This study analyzes the future and for the following minerals and als in 1985 and in 2000 that are ortant inputs for industrial output oughout the world: aluminum, chrome, alt, copper, iron, manganese, nickel, tinum, steel, tin, tungsten and zinc." imates of future demand are provided this study.

US-620

Catalog of Information on Water Data. U.S. Department of the Interior, Geological Survey, Office of Water Data Coordination, National Center, Mail Stop 417, Reston, VA 22092

This catalog is a "biennial 21-volume index of data collected by streamflow and water quality measurement stations in each of 21 water resource regions. Information is based on reports to the Office of Water Data Coordination by federal, state, and local agencies, and private organizations with direct field or laboratory collection programs. (This) catalog is intended to be a central index of all water data activities in each water region (and therefore is not a file of the actual water data which must be obtained from the reporting agencies). (Congressional Information Service, American Statistics Index, Third Annual Supplement, 1977, p. 536). Information indexed includes data on streamflow and stage measurement, surface water quality, and ground water quality. See also US-810.

US-621

Census of Wholesale Trade. U.S. Department of Commerce, Bureau of the Census, Washington, DC 20233

This census, taken for years ending in "2" and "7", "provides detailed data on the number of establishments, and their employment and payrolls, legal organization and type of operation, size, and inventories, and expenses. Data are shown by kind of business and for states, SMSA's, and specified counties and cities. Results of the census are published first as preliminary reports for each state. These data are superseded by final reports (Area Series, Subject Series and Wholesale Commodity Line Sales)." (Congressional Information Service, American Statistics Index, Third Annual Supplement, 1977, p. 258). These data are also available on computer tape from the Data User Services Division of the Bureau of the Census.

US-622

Census of Retail Trade. U.S. Department of Commerce, Bureau of the Census, Washington, DC 20233

This census, taken for years ending in "2" and "7", "provides detailed data on the number of establishments, and their sales, employment and payrolls, legal organization, and size. Data are shown by kind of business and for states, SMSA's, counties, and specified cities. Results of the census are published first as preliminary reports for each state. The data are superseded by final reports (Area Series, Subject Series, Retail Merchandise Line Sales Series, and Major Retail Center Statistics Series) (Congressional Information Service, American Statistics Index, Third Annual Supplement, 1977, p. 257). These data are also available on computer tape from the Data User Services Division of the Bureau of the Census.

US-623

Long Term Economic Growth. U.S. Department of Commerce, Bureau of Economic Analysis, Washington, DC 20230

"This report brings together approximately 1,200 annual economic time series which are useful for studying economic growth. These series are carried back as far as 1860, whenever possible." Aggregate output, input and productivity, and regional and industry trends are some of the series examined. This publication is updated approximately every fifth year with the next edition scheduled for distribution in 1980.

US-624

Timber Resource Statistics for the Copper River Inventory Unit, Alaska, 1968. Karl Hegg. 1975. Resource Bulletin PNW-62. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, P.O. Box 3141, Portland, OR 97208

"This resource bulletin reports on the findings of the first intensive inventory of lands with commercial forest potential within the Copper River Valley drainage system."

US-625

The Timber Resources of the Inland Empire Area, Washington. 1974. H. Arbogast. Resource Bulletin PNW-50. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, P.O. Box 3141, Portland, OR 97208

"This report presents the findings of the latest inventory of the timber resources of Pend Oreille, Spokane, Stevens, Ferry, Lincoln, Whitman, Asotin, Garfield, Columbia, Adams, Franklin, and Walla Walla Counties, Washington. Accompanying the detailed tables of forest area, volume, growth, and mortality statistics is an analysis of the present timber resource, with emphasis on conditions that affect present and future timber production.

US-626

Forest Statistics for the Upper Koyukuk River, Alaska, 1971. 1974. Karl Hegg. Resource Bulletin PNW-54. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, P.O. Box 3141, Portland, OR 97208

"This resource bulletin reports the findings of the first intensive forest inventory of the upper Koyukuk River drainage in northcentral Alaska, Standa[rd] Forest Survey tables are presented plus [a] limited amount of data from an operable noncommercial class."

US-627

The Timber Resources of the Blue Mounta[in] Area, Oregon. 1975. Charles Bolsinger and J. Berger. Resource Bulletin PNW-5[?] U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, P.O. Box 3141 Portland, OR 97208.

"This report summarizes the finding[s] of a timber resource inventory in Baker, Grant, Harney, Malheur, Morrow, Umatill[a],

ion, and Wallowa Counties in Oregon. tailed tables of forest area, timber lume, growth, mortality, and cut are esented, along with a discussion of the esent timber resource situation."

US-628

unty Business Patterns. U.S. Department of Commerce, Bureau of the Census, shington, DC 20233

This is a series of 52 annual reports (ne for the nation, each state and the strict of Columbia) that presents unty level data on business establishments, employment, and payrolls, by idustry.

US-629

nthly Energy Review. U.S. Department Energy, Energy Information Administation, National Energy Information Cnter, Washington, DC 20461

This is a monthly report on the principal energy fuels in the United States. oduction, consumption, imports, stocks ad prices are among the statistics presnted. Prior to October, 1977, this reprt was issued by the now abolished deral Energy Administration.

US-630

deral Energy Data System (FEDS), Stastical Summary. U.S. Department of ergy, Energy Information Administation, Washington, DC 20461

This annual report, first issued in 178, presents detailed energy consmption data by consuming sector, energy surce, region, and state.

US-631

ergy Information Administration Annual port to Congress, U.S. Department of ergy, Energy Information Administation, Washington, DC 20461

This annual report, first issued for 177, describes the activities of the ergy Information Administration, and esents data on energy production, consumption, and prices. The report also includes data on projections of energy supply and demand.

US-632

Annual Report of Lands Under Control of the U.S. Fish and Wildlife Service. U.S. Department of the Interior, Fish and Wildlife Service, Washington, DC 20242

This annual report lists acreage of different categories of land managed by the Fish and Wildlife Service. Data are presented by state and unit.

US-633

Lumber Prices and the Lumber Products Industry: Interim Report. 1977. Thomas Lenard et al. Executive Office of the President, Council on Wage and Price Stability, 726 Jackson Place N.W., Washington, DC 20506

This report describes and evaluates the structure of the lumber products industry, and summarizes recent trends in lumber prices and production. "Data on Timber Products, Pricing, and Housing" and "Projections of Demand for Housing and Softwood Timber, 1980-1990" are included in two appendixes.

US-634

Cost Estimating Guide for Road Construction. 1978. U.S. Department of Agriculture, Forest Service, Division of Engineering, Region 4, 324 25th St., Ogden, UT 84401

"This Cost Estimating Guide is intended to establish procedures and standardize methods of making estimates for road construction. The Guide has been developed to reflect the costs of an independent contractor doing public works construction. Costs included are average costs for work done on Region 4 projects." The Guide will be updated periodically.

US-635

Range Management Practices: Investment Costs, 1970. 1972. G. Duran and H.

Kaiser. Agriculture Handbook No. 435. U.S. Department of Agriculture, Forest Service, P.O. Box 2417, Washington, DC 20013.

"This publication defines and tabulates investment costs and life expectancies for the 18 range management practices used in the Forest-Range Environmental Study (FRES). Values were determined from published and unpublished sources and from experience of USDA Forest Service experts in this field."

US-636

The Nation's Water Resources: The National Water Assessment. U.S. Water Resources Council, 2120 L St. N.W., Washington, DC 20037

"The Water Resources Planning Act of 1965 (Public Law 89-80) directs that the Water Resources Council maintain a continuing study of the adequacy of the Nation's water and related land resources to meet present and future requirements for these resources." The Act requires that the Council "prepare an assessment [of the nation's water and related land resources] biennially, or at such less frequent intervals as the Council may determine." At this writing assessments have been prepared in 1968 and 1978. The multivolume 1978 Assessment is organized in the following fashion:

Summary: - provides an overview of the entire final report with emphasis on critical water management considerations and findings and conclusions.

Part I: INTRODUCTION: outlines the authority, purpose, plan of study, and historical perspective.

Part II. WATER MANAGEMENT PROBLEM PROFILES: identifies the 10 most critical issues and their implications.

Part II. FUNCTIONAL WATER USES: focuses on the national perspectives regarding existing and future (1985 and 2000) requirements for water to meet offstream, instream, and flow management needs for 11 major functional use categories. State-Regional and Federal perspectives are compared.

Part IV. WATER SUPPLY AND WATER QUALITY CONSIDERATIONS: analyzes the adequacy of freshwater supplies to meet existing and future requirements. Part IV presents a national water budget; quantifies surface and ground waters, storage, and transfers of water within and among regions; describes regional requirements and compares them to supplies; describes water quality conditions; and briefly discusses the legal and institutional aspects of allocation.

PART V. REGIONAL SUMMARIES: presents a summary of conditions in each of the 21 water resource regions describing major regional issues and problem areas. This part is supported by 21 individual regional reports each with recommendations from the State-Regional perspective regarding planning, research, data needs, and the Federal role.

STATISTICAL APPENDIX A-1: contains the economic, social and environmental data for 1975, 1985, and 2000, on which the water supply and use projections are based.

STATISTICAL APPENDIX A-2: contains basic data on water supply and use for 1975, 1985, and 2000. It includes streamflow information, reservoir storage capacity, ground water data, interbasin imports and exports, and instream flow approximations.

STATISTICAL APPENDIX A-3: contains analyses of the water supply and use data."

US-637

Forest Statistics of the U.S., 1977. 1978. U.S. Department of Agriculture Forest Service, P.O. Box 2417, Washington, DC 20013

"The statistics in this report update ilar compilations contained in earlier est Service reports on the timber sit- ion in the United States. Statistics 1952, 1962, and 1970, are also inclu- in some tables to indicate trends in nation's forest resources."

US-638

estock Report. U.S. Department of Ag- ulture, Oregon Crop and Livestock Re- ting Service, 1735 Federal Bldg., 1220 . 3rd Ave., Portland, OR 97204

Several short reports on livestock Oregon are issued at various intervals ing the year including "Cattle on d," "Wool Production," "Sheep on d," "Livestock Production and Value," ttle, Sheep and Hog Inventory," and vestock Slaughter." Additional infor- ion is available on request.

US-639

th Dakota Crop and Livestock Reporter. . Department of Agriculture, South ota Crop and Livestock Reporting vice, 3528 South Western Ave., Box U, ux Falls, SD 57101

This report, issued twice monthly, relevant agriculture statistics for th Dakota, including information on estock. Additional data are avail- e on request.

US-640

aii's Timber Resources, 1970. 1978. vin E. Metcalf, Robert E. Nelson, in Q. P. Petteys, and John M. Berger. ource Bulletin PSW-15. U.S. Depart- t of Agriculture, Forest Service, Pa- ic Southwest Forest and Range Experi- t Station, P.O. Box 245, Berkeley, 94701

This report presents the results of a est survey of Hawaii's forests con- ted between 1969 and 1971. Timber ume and area statistics are included the report.

US-641

Current Population Reports. U.S. Department of Commerce, Bureau of the Census, Washington, DC 20233

These publications are issued in several series of individual reports presenting current, historical, or projected statistics on various population subjects. At this writing the following series are published:

Population Characteristics
This series of reports is issued at irregular intervals throughout the year and deal with various U.S. population characteristics including mobility, education and family characteristics.

Special Studies
This series of reports, issued irregularly, present data on special subjects.

Population Estimates and Projections
This series of reports is issued as monthly summaries presenting estimates of U.S. population and at irregular intervals presenting more detailed data, dealing with population estimates and projections for the U.S., regional areas and states.

Federal-State Cooperative Program for Population Estimates
This is a series of reports, presenting the latest population estimates. Report titles read Estimates of the Population of (state) Counties and Metropolitan Areas.

Farm Population
This annual report contains data on population and other characteristics of the U.S. population living on farms.

Special Censuses
This series presents data of special censuses taken of counties or cities.

Consumer Income
This series of periodic and special reports present data of various socioeconomic characteristics by income.

US-642

Prospects for Sawtimber Output in California's North Coast, 1975-2000. 1978. Daniel Oswald. Resource Bulletin PNW-74. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, P.O. Box 3141, Portland, OR 97208

"This report summarizes a study of sawtimber output alternatives for California's North Coast. Eleven "scenarios" of softwood sawtimber output from private lands are presented. The scenarios differ as to assumptions about rates and patterns of harvest and objectives pertaining to levels of output. Prospects for output from public lands are also discussed."

US-643

Forest Area and Timber Resources of the San Joaquin Resource Area. 1978. Charles Bolsinger. Resource Bulletin PNW-74. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, P.O. Box 3141, Portland, OR 97208

"This report presents statistics on forest area and timber volume and a description of the recent and future timber situations in Alpine, Amador, Calaveras, Fresno, Kern, Kings, Madera, Mariposa, Merced, Mono, San Joaquin, Stanislaus, Tulare, and Tuolumne Counties, California."

US-644

Current Industrial Reports. U.S. Department of Commerce, Bureau of the Census. Washington, DC 20233

These are more than 100 monthly, quarterly and annual reports presenting industry data for thousands of manufactured products in the U.S. Most reports have production, consumption and trade data. Other information relevant to that product is also included. Most reports present data for the entire U.S.; some reports have data for smaller geographical entities. Some relevant reports include:

1) Hardwood Plywood
2) Softwood Plywood
3) Lumber, Production and Mill Stocs
4) Pulp, Paper and Board

US-645

Forecast of Likely U.S. Energy Supply/Demand Balances for 1985 and 2000 and Implications for U.S. Energy Policy. 1977. Joseph Gustaferro, Michael Maher and Roswell Wing. U.S. Department of Commerce, Domestic and International Business Administration, Washington, DC 20230

(Available through NTIS PB-266 240)

This report develops "a forecast of the most likely U.S. energy supply/demad balance for 1985 and the year 2000, basd on the expected impact of U.S. policies and trends in key energy areas now in force."

US-646

Waterfowl Status Report. U.S. Department of the Interior, Fish and Wildlife Service, Office of Migratory Bird Management, Laurel, MD 20811

This annual report contains the results of waterfowl breeding population and production surveys, and waterfowl harvest surveys. The information is provided by the U.S. Fish and Wildlife Service, the Canadian Wildlife Service and cooperating state agencies. The report is issued in the Special Scientif Report Wildlife Series.

US-647

Distribution in States and Counties of Waterfowl Species Harvested During 196- 70 Hunting Seasons. 1975. Samuel Carny and Michael Sorensen. Special Scientic Report-Wildlife No. 187. U.S. Department of the Interior, Fish and Wildife Service, Office of Migratory Bird Manageme, Laurel, MD 20811

This report presents data estimati by species the average number of water

wl harvested during the 1961-70 hunting asons for each county in the continen-l United States.

US-648

ergy Availabilities for State and Local velopment. U.S. Department of Energy, Ridge National Laboratory, Oak Ridge, 37830

This annual report presents histori-l and projected data estimating demand, pply and net imports of seven fuel es for Bureau of Economic Analysis gions, states, census regions, and the ion. This report is under the spon-ship of the Economic Development Ad-nistration.

US-649

l Use Energy Consumption Data Base: ies 1 Tables. 1978. U.S. Department Energy, Energy Information Adminis-tion, Division of Consumption Studies, shington, DC 20461

"This report presents a series of bles which categorize national energy nsumption in 1974 by economic sector, major industries within certain sec-s, by end use, by fuel, and by geo-phic area. The data base contains ormation at the national, census ision, and state levels."

US-650

ulation Projections for Area Planning: ibliography with Abstracts. U.S. De-tment of Commerce, National Technical ormation Service, 5285 Port Royal Rd., ingfield, VA 22161

Bibliographies are issued periodi-ly citing reports on predictions of ulation growth or change in state, re-nal, county, or municipal areas. Re-ts on projections for area economic lysis, employment, land and resource , health, education, energy, and nsportation needs and planning as ected by population change are luded.

US-651

Fisheries of the United States. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Washington, DC 20235

This annual report presents preliminary data on the U.S. fishing industry, including data on U.S. commercial landings, U.S. marine recreational fisheries and foreign trade. This report is published in the Current Fishery Statistics series. Final data are published in Fishery Statistics of the United States (US-652).

US-652

Fishery Statistics of the United States. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Washington, DC 20235

This annual report contains a review of U.S. commercial fishery statistics. "These statistics include data on the volume and value of landed catches, employment, quantity of gear operated, and number of fishing craft. Also included are data on the volume and value of production of processed fishery products, freezings and cold storage holdings, and foreign trade in fishery commodities." This publication is issued in the Statistical Digest series. Preliminary data were published at an earlier date in Fisheries of the United States (US-651).

US-653

Timber Resources of West-Central Oregon. 1978. David Jacobs. Resource Bulletin PNW-76. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, P.O. Box 3141, Portland, OR 97208

"This report presents statistics from a 1975 timber resource inventory of Benton, Lane, Lincoln, and Linn Counties, Oregon. Tables are of forest area, timber volume, growth, and mortality.

US-654

Forest Products Price Report. U.S. Department of Agriculture, Washington Crop Reporting Service, 909 First Ave., Rm. 3039, Seattle, WA 98174

This bimonthly report summarizes forest product prices by item and area in the State of Washington. The reports are issued in cooperation with the U.S. Forest Service, the State of Washington Department of Natural Resources, Washington State University, Cooperative Extension Service, and Washington State University, Department of Forestry and Range Management.

US-655

Tables of Compound-Discount Interest Rate Multipliers for Evaluating Forestry Investments. 1971. A. Lundgren. Research Paper NC-51. U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, 1992 Folwell Ave., St. Paul, MN 55108

"Tables, prepared by computer, are presented for 10 selected compound-discount interest rate multipliers commonly used in financial analyses of forestry investments. Two sets of tables are given for each of the 10 multipliers. The first set gives multipliers for each year from 1 to 40 years; the second set gives multipliers at 5-year intevals from 5 to 160 years. Multipliers are given for 24 selected interest rates from 0.5 to 30 percent. Each table is briefly explained and an example of its use is given. These tables had been issued previously in multilithed form."

US-656

Grazing on National Forest System Lands: Costs of Increasing Capacity in the Northern Region. 1978. Joseph Horvath, Dennis Schweitzer, and Enoch Bell. Research Paper INT-215. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, 507 25th St., Ogden, UT 84401

"Feasibility of increasing grazing capacity through additional range improvements was investigated in the Northern Region of the U.S. Department of Agriculture Forest Service. Sample grazing allotments on representative Ranger Districts were evaluated by questionnaire. Results of the survey included estimates of additional livestoc[k] that could be grazed, cost of additiona[l] improvements, and value of existing improvements."

US-657

Dispersed Recreation on Three Forest Ro[ad] Systems in Washington and Oregon: Firs[t] Year Data. 1976. John Hendee, Mack Hogans, and Russell Koch. Research Not[e] PNW-280. U.S. Department of Agricultur[e], Forest Service, Pacific Northwest Fores[t] and Range Experiment Station, P.O. Box 3141, Portland, OR 97208

"Data produced during the 1st year [o]f a 3-year study of dispersed road recreation along forest roads in Washington and Oregon are described in this report"

US-658

Census of Agriculture. U.S. Department of Commerce, Bureau of the Census, Washington, DC 20233

This census presents detailed data [o]n the agriculture industry of the United States. The census is issued in severa[l] volumes, including one containing separate reports for each state (with much [o]f the data presented by county) and another with data by subject. This censu[s] has been taken every five years ending [i]n "4" and "9"; in the future it will be taken in years ending in "2" and "7".

US-659

Productivity Indexes for Selected Indus[s]tries, 1978 Edition. 1978. Bulletin 2002. U.S. Department of Labor, Burea[u] of Labor Statistics, Washington, DC 20210

"This bulletin updates through 197[7] indexes of output per employee-hour an[d] output per employee for the industries currently included in the U.S. Government's productivity measurement progra[m]

industries for which output per ployee-hour indexes are shown are not essarily a representative cross-tion of U.S. industry. They should be combined, therefore, to obtain an rall measure for the entire U.S. econ- or for any sector. Each index is in-nded to represent only the change in put per employee-hour for the desig-ed industry or combination of indus-es. However, the Bureau of Labor Sta-tics does publish indexes of output hour of all persons and related mea-es for the private business sector and nonfarm business, manufacturing, and financial corporate sectors. These ductivity series show the relationship ween gross product originating in se sectors and employment and hours. e data are presented in the Bureau of or Statistics press release, Produc-ity and Costs (twice quarterly), in Monthly Labor Review (US-546), and in loyment and Earnings (US-548))."

US-660

Nation's Range Resources: A Forest-ge Environmental Study. 1972. Forest ource Report No. 19. U.S. Department Agriculture, Forest Service, P.O. Box 7, Washington, DC 20013.

"A system was developed for catego-ing the forest and range area of the coterminous United States into major systems. These ecosystems were di-ded according to ownership, producti-y, and condition into resource units, d area determined, and 1970 grazing duction and 21 other outputs esti-ed. Yield of all outputs in each of resource units was estimated under simulated levels of management. De-nd was derived for livestock grazing estimated for other forest-range out-s. An analytical system was developed h a minimum cost objective function used to suggest management mixes to ieve national goals for forest-range estock production at minimum cost when ified by environmental or social con-erations. Policy alternatives for ting long-run policy objectives were luated and conclusions drawn about est-range grazing."

US-661

Basic Estimated Capital Investment and Operating Costs for Underground Bituminous Coal Mines: Mines With Annual Production of 1.06 to 4.99 Million Tons From a 72-Inch Coalbed. 1976. Sidney Katell, E.L. Hemingway, and L.H. Berkshire. Information Circular 8682A. U.S. Department of the Interior, Bureau of Mines, 2401 E St. N.W., Washington, DC 20241

"This study estimates capital investment, operating costs, and selling prices for four underground bituminous mines producing coal with annual production ranging from 1.06 to 4.99 million tons. It is assumed that the mines have a 20-year life. Wages and union welfare payments are considered as of December 6, 1974, under the Bituminous Wage Agreement of 1974, and costs for material and equipment are based on 1975 indexes." The U.S. Department of Energy, Process Evaluation Office (P.O. Box 863, Morgantown, WV 26505), plans to update this publication on a periodical basis.

US-662

Basic Estimated Capital Investment and Operating Costs for Underground Bituminous Coal Mines: Mines With Annual Production of 1.03 to 3.09 Million Tons From a 48-Inch Coalbed. 1975. Sidney Katell, E.L. Hemingway, and L.H. Berkshire. Information Circular 8689. U.S. Department of the Interior, Bureau of Mines, 2401 E St. N.W., Washington, DC 20241

"This study estimates capital investment, operating costs, and selling prices for three underground bituminous mines producing coal with annual production ranging from 1.03 to 3.09 million tons. It is assumed that the mines have a 20-year life. Wages and union welfare payments are considered as of December 6, 1974, under the Bituminous Wage Agreement of 1974, and costs for material and equipment are based on 1975 indexes." The U.S. Department of Energy, Process Evaluation Office (P.O. Box 863, Morgantown, WV 26505), plans to update this publication on a periodical basis.

US-663

Basic Estimated Capital Investment and Operating Costs For Underground Bituminous Coal Mines Utilizing a Continuous Mining System: Mines With Annual Production of 1.188 and 2.376 MMtpy ROM From 72-Inch Coalbed. 1978. John Duda. U.S. Department of Energy, Process Evaluation Office, P.O. Box 863, Morgantown, WV 26505

"This study estimates typical capital investments, operating costs, and selling prices for underground bituminous coal mines utilizing continuous miners and sized for annual production rates of 1.188 and 2.376 million tons ROM (run-of-mine). Wages and union welfare payments are those that went into effect under the National Bituminous Coal Wage Agreement of 1978, effective March 27, 1978. Costs of materials and equipment are based on first quarter 1978 indexes. It is assumed that the mines have a 20-year life." Plans are to update this publication on a regular basis.

US-664

Basic Estimated Capital Investment and Operating Costs for Underground Bituminous Coal Mines Developed for Longwall Mining: Mines With Annual Production of 1.5 to 3 Million Tons by Longwall Mining From an 84-Inch Coalbed. 1976. John Duda and E.L. Hemingway. Information Circular 8715. U.S. Department of the Interior, Bureau of Mines, 2401 E St. N.W., Washington, DC 20241

"This study estimates the required capital investment, operating costs, and selling prices for two hypothetical mines designed to produce 1.5 and 3 million tons per year by using a longwall system in conjunction with a continuous-mining system. The coal properties being mined are assumed capable of sustaining a 20-year production period. Wages and union welfare payments used in this study are those in effect as of December 6, 1975, as set forth under the National Bituminous Coal Wage Agreement of 1974. Costs of materials and equipment are based on January 1976 indexes. "The U.S. Department of Energy, Process Evaluation Office (P.O. Box 863, Morgantown, WV 26505), plans to update this publication on a periodical basis.

US-665

Basic Estimated Capital Investment and Operating Costs for Underground Bituminous Coal Mines Developed for Longwall Mining: Mines With Annual Production of 1.3 to 2.6 Million Tons by Longwall Mining From a 48-Inch Coalbed. 1976. John Duda and E.L. Hemingway. Information Circular 8720. U.S. Department of the Interior, Bureau of Mines, 2401 E St N.W., Washington, DC 20241

"This study estimates the required capital investment, operating costs, and selling prices for two hypothetical mines designed to produce 1.3 and 2.6 million tons per year by using a longwall system in conjunction with a continuous-mining system. The coal properties being mined are assumed capable of sustaining a 20-year production period. Wages and union welfare payments used in this study are those in effect as of December 6, 1975, as set forth under the National Bituminous Coal Wage Agreement of 1974. Costs of materials and equipment are based on January 1976 indexes. "The U.S. Department of Energy, Process Evaluation Office (P.O. Box 863, Morgantown, WV 26505), plans to update this publication on a periodical basis.

US-666

Basic Estimated Capital Investment and Operating Costs for Three Coal Strip Mines. 1977. L.H. Berkshire and E.L. Hemingway. U.S. Department of Energy, Process Evaluation Office, P.O. Box 863 Morgantown, WV 26505

"This study estimates typical capital investments, operating costs, and selling prices for hypothetical bituminous coal strip mines in the Eastern and Interior provinces and an operation in the Northern Great Plains province. Annual production for the Eastern province mine is 150,000 tons; for the Interior and Northern Great Plains provinces mines it is 3.36 million and 5 million tons respectively. Wages and union wel

are payments for the Eastern and Interior mines are those that went into effect December 6, 1976, as prescribed under the terms of the Bituminous Wage Agreement of 1974; for the Northern Great Plains province mine, the wages and union welfare payments are those outlined in the Western Surface Coal Mine Agreement of 1975. The wages and related costs are adjusted to reflect cost-of-living increases to the third quarter of 1977. Equipment and naterial costs are also adjusted to the third quarter of 1977, using an index furnished by equipment manufacturers. It is assumed that the mines have a 20-year life. Selling prices were determined for each mine--one based on 12-, 15-, and 20-percent returns on equity and the other based on the same returns with a debt-equity split of 1:2. These studies are considered typical for the areas involved. Costs vary considerably depending on specific locations." Plans are to update this publication on a regular basis.

US-667

Basic Estimated Capital Investment and Operation Costs For Subbituminous and Lignite Coal Strip Mines. 1979. U.S. Department of Energy, Process Evaluation Office, P.O. Box 863, Morgantown, WV 26505

This report estimates typical capital investments, operating costs, and the required selling prices for coal produced from hypothetical subbituminous and lignite coal strip mines in the Northern Great Plains province. Annual production for subbituminous mine is 4 million tons; for the lignite mine, it is 3 and 5 million tons. This publication will be updated on a periodical basis.

US-668

Statistics of Income: Individual Income Tax Returns. U.S. Department of the Treasury, Internal Revenue Service, 1111 Constitution Ave., Washington, DC 20224

"This report annually contains data on sources of income, adjusted gross income, exemptions, total deductions, taxable income, income tax, tax credits, self-employment tax, tax withheld, and tax payments. Also shown are selected income and tax items for States." Data are published approximately three years after year of coverage. Preliminary, summary data are published approximately two years after year of coverage (Preliminary Report, Statistics of Income: Individual Income Tax Returns).

US-669

Supplemental Report, Statistics of Income: Small Area Data, Individual Income Tax Returns. U.S. Department of the Treasury, Internal Revenue Service, 1111 Constitution Ave., Washington, DC 20224

"In this (biennial) supplemental report to the Statistics of Income Series, income and tax data from individual tax returns are shown for local areas. Number of returns, number of exemptions, and amounts of income and tax, classified by size of adjusted gross income are presented for states, counties and selected standard metropolitan statistical areas."

US-670

Major Uses of Land in the United States. U.S. Department of Agriculture, Economics, Statistics and Cooperatives Service, Washington, DC 20250

"This report summarizes the extent and distribution of major land uses in the United States and, by comparison with earlier land use inventories, documents the changes and trends in land utilization. The entire land area of the country is broadly classed as cropland, grassland pasture, forest land, special uses, and other land. Numerous subclasses reflect component agricultural and nonagricultural uses. Distribution patterns and trends are shown by aggregating and comparing acreages of individual uses at the regional and national levels. State-by-state acreages in various component uses are presented in appendix tables. Among principal sources of data used were reports and records of the Bureau of the Census, U.S. Department of Commerce; Bureau of Land Management, U.S. Department of the Interior; and

several agencies of the U.S. Department of Agriculture. Supplemental data were obtained from numerous other Federal and State agencies." The latest report was issued in 1973 with 1969 data by the Economic Research Service, the predecessor of the Economics, Statistics and Cooperatives Service. It is expected that updated reports will be issued in the future.

US-671

Harvesting Costs for Mechanized Thinning Systems in Slash Pine Plantations. 1978. James Granskog. Research Paper SO-141. U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, Rm. T-10210, Postal Services Bldg., 701 Loyola Ave., New Orleans, LA 70113

"Harvesting costs of four tree harvester systems are estimated for row thinning slash pine plantations. Systems incorporating a full-tree type harvester had lower harvesting costs per cord than shortwood and tree-length harvester systems in 15-year-old plantations."

US-672

Bureau of Land Management: Nevada Statistics. U.S. Department of the Interior, Bureau of Land Management, 300 Booth St., Rm. 3008, Reno, NV 89509

This annual publication summarizes the activities of the Bureau of Land Management in Nevada during the preceding year. Sections include minerals management, range management, recreation management, and woodland management.

US-673

Coal Surface Mining Reclamation Costs in the Western United States. 1977. Franklin Persse, David Lockard, and Alec Lindquist. Information Circular 8737. U.S. Department of the Interior, Bureau of Mines, 2401 E St. N.W., Washington, DC 20241

This report estimates "reclamation costs for 13 surface coal mines in nine states west of the Mississippi River. With the exception of the Pacific Coast coal province, at least one mine in eac of the western coal provinces was studied. Cost estimates were made usin standard estimating procedures from dat obtained from company records, intervies with industry personnel, and onsite observations. Estimated costs are presented in four categories which represet the four phases of mined-land reclamation: (1) Design, engineering, and overhead; (2) bond and permit fees; (3) backfilling and grading; and (4) revegetation. Estimated costs as of the firs quarter of 1976 are expressed as averages and ranges in terms of per acre, per ton of coal produced, and per millin Btu."

US-801

U.S. Department of the Interior, Natiol Park Service, Regional Offices (listed n App. A)

"Monthly Public Use Reports" for eh park are available in regional offices f the National Park Service. Data incluc visits, and special use data. Data are for the month and year-to-date (see als US-562).

US-802

"Wildlife Annual Report," U.S. Departmet of the Interior, Bureau of Land Management, Washington, DC 20240

Annual internal report containing population estimates and harvests. Als lists inventories that have been completed for specific species.

US-803

Recreation Information Management Syste (RIM), U.S. Department of Agriculture, Forest Service, Division of Recreation, RIM Center, P.O. Box 2417, Washington, DC 20013

This is a Forest Service computer-oriented recreation management system that provides a wide range of informat n useful for recreation planning and management. Information is available on l

creation sites and areas of the Na- onal Forest System, including their ological and physical characteristics d condition, their capacity, and the lume and kinds of use they support. ta is stored in a relatively non- gregated fashion (e.g., by county, nger District, type of individual cility and site, etc.) and conse- ently output can be produced in many mbinations needed by RIM users. For ditional information contact the RIM nter, all Forest Service Regional fices (addresses are listed in Appen- x A), Recreation Staff (see US-804), or fer to the following Forest Service blications:

1) RIM Handbook (Forest Service Hand- ok 2309.11)

2) Recreation Management (section on M, Forest Service Manual 2312)

3) Recreation Information Management (raining guide for those not working rectly with the RIM System, issued by e Recreation Staff)

US-804

S. Department of Agriculture, Forest Srvice, Recreation Management Staff.

Unpublished recreation data available upon request from Forest Service Regional Ofices, Recreation Staff (addresses are lsted in Appendix A). These statistics ae output from the Recreation Informaton Management System (see US-803). Te following are some of the types of da available:

1) "Estimated National Forest Recreation Use, Service-Wide Summary: By Kinds of Sites and Areas, and By Activities"

2) "Estimated National Forest Recreation Use of Classified Areas: By Kind of Sites and Areas, and By Activities"

3) "Recreation Sites, Areas, Improvements and Services in the National Forest System"

4) "Recreation Use of the National Forests" (historical visitation data)

5) "Regional Summary of Recreation Use"
--"Summary of Activities"
--"Use of Developed Recreation Sites"
--"Use of Dispersed Recreation Areas"

6) "Relative Standings of the National Forests According to Amount of Visitor-Days of Use"

7) "State Summary of Recreation Use"
--"Use of Developed Recreation Sites"
--"Use of Dispersed Recreation Areas"
--"Summary of Activities"

8) "Use of National Forest Units, National Wilderness Preservation System"

9) "A Summary of Forest Service Developed Sites, Number, Capacity, and Size"

10) Data is generally available on individual units within each region.

US-805

U.S. Department of the Interior, Bureau of Land Management, Washington, DC 20240

Unpublished data available upon request dealing with payments to local governments in lieu of taxes, including Forest Service payments, (as required by Public Law 94-565) and resource activities on BLM lands. Some of the resource data are also available in published form in Public Land Statistics (US-530).

US-806

Computerized Resources Information System (CRIB). U.S. Department of Interior, Geological Survey, 1200 South Eads St., Arlington, VA 22202

CRIB is the mineral resources data

bank of the U.S. Geological Survey and is "available for public use through the computer facilities of the University of Oklahoma and the General Electric Company. CRIB consists of a set of variable-length records on the metallic and nonmetallic mineral resources of the United States and other countries. The [bank] contains information on mineral deposits and mineral commodities. Some topics covered are: deposit, geology, production, reserves, potential resources, and references" (U.S. Department of Interior, Geological Survey, Description of Individual Data Items and Codes in CRIB, Geological Survey Circular 755-B).

US-807

Bureau of Labor Statistics Data Bank. U.S. Department of Labor, Bureau of Labor Statistics, Division of Planning and Financial Management, 441 G St. N.W., Washington, DC 20212

The Bureau of Labor Statistics (BLS) has established a Data Bank containing the summary data generated by statistical surveys from BLS and other data producers. The Data Bank is divided into a number of separate data files, each containing statistics on a particular subject. Further information may be obtained by contacting BLS or by referring to BLS Report 507, issued in 1978, BLS Data Bank Files and Statistical Routines. This publication is a "catalogue of published and unpublished material available in computerized form from the BLS data bank. (It) contains (a) description of the content of 21 data files, with references to publications that present the data and describe the methodology used. (It) also describes BLS data processing capability and statistical and cross-tabulation computer-routines available" (Congressional Information Service. 1978. American statistics index supplement No. 3: abstracts. p. 64).

US-808

U.S. Department of Commerce, Bureau of Economic Analysis, Washington, D.C. 20230

The Bureau of Economic Analysis (BEA) maintains several information systems, whose output can be useful for wildland planning and management. Data of a general nature are published in several reports including Survey of Current Business (US-529), Long Term Economic Growth (US-623), Business Conditions Digest and in input-output data publications (US-594). Data in greater detail than what appears in publications are generally available upon request. Inquiries should be referred to Information Services of B.E.A. or the Regional Economic Measurement Division (this division is especially useful for detailed county data). At this writing some of the information systems are:

(1) "Economic Accounts of the United States"
"This system includes numerous subsystems which produce various elements of the national accounts. The major subsystems include the national income and product accounts system which focuses on the gross national product and provides an overall view of the economic process; the input-output accounts system which describes industrial interactions; and the regional accounts systems which provide measurements and projections of economic activity by State, metropolitan area, and county. Primary sources (for this system) include the Bureau of Labor Statistics (wholesale and consumer price indices, various employment series), the Internal Revenue Service (statistics of income, self-employed income data), the Bureau of the Census (Retail and Wholesale Trade data, agricultural and transportation statistics), State Unemployment Insurance Offices (county income data), and private companies (plant and equipment expenditure, foreign investment)" (U.S. General Accounting Office, 197[illegible] Federal Information Sources and Systems, p. 51).

(2) "U.S. Interindustry Transactions System"
"This system provides an in-depth analysis of the various interrelationships that exist among the industries of the United States. The output is essential to all studies of the cost-price structure of the economy and to productivity analysis. It is used to examine the effect of changes in the level and composition of consumer, business, foreign, and Government demand on industrial activity and the effect of price changes in individual industries on the prices of other industries and on the price level as a whole" (U.S. General Accounting Office, 1977, Federal Information Sources and Systems, p. 51). See also US-594.

(3) "U.S. Regional Economic Measurements System"
"This system measures economic activity in the United States by geographic area and retrieves and distributes these measures for any geographic grouping desired. The estimates which are developed constitute the most comprehensive set of economic activity data available on a regional or local area basis. (The) system develops estimates of personal income by type and by industry for each State, standard metropolitan statistical area (SMSA) and county. The system also develops annual measures of employment for States, SMSA's and counties that are consistent with the income estimates" (U.S. General Accounting Office, 1977, Federal Information Sources and Systems, p. 52).

(4) "U.S. Regional Economic Accounts System"
"This system is a series of interrelated subsystems that develop projections of economic activity by geographic area, review and analyze the current economic activities in and between these economic areas, and are in the process of producing regional income and product accounts consistent with the national accounts. The projection subsystem provides long-range projections of income, employment, and population for about 950 local areas. These areas are tailored to the requirements of public and private users and consist of states, SMSA's and water resources and other economic planning areas" (U.S. General Accounting Office, 1977 Federal Information Sources and Systems, p. 52).

US-809

National Water Data Storage and Retrieval System (WATSTORE), U.S. Department of the Interior, Geological Survey, Chief Hydrologist, 437 National Center, Reston, VA 22091

"WATSTORE was established to store data collected as a result of measuring and quantifying the occurrence and quality of U.S. water resources and the effect of development and utilization on those resources. The data base includes surface water stage and discharge; chemical quality parameters; radiochemistry; sediment; pesticide and certain biological concentrations in water; ground water levels; geologic data describing the framework in which ground water occurs; flood frequency, and flood inundation mapping. The data are generally updated on a monthly basis and are referenced by state, county, and latitude-longitude" (U.S. General Accounting Office, 1977, Federal Information Sources and Systems, p. 130). On request, WATSTORE can provide an assortment of useful data products to meet many needs. These products range from computer-printed tables and graphs to complex statistical analyses. Information about the availability of specific types of data, the acquistion of data or products, and user charges can be obtained from the above address or from the Water Resources Division's district offices located throughout the country (see App. A).

US-810

National Water Data Exchange (NAWDEX), U.S. Department of the Interior, Geological Survey, 421 National Center, Reston, VA 22092

"NAWDEX is a national confederation of water-oriented organizations working together to improve access to water data. Its primary objective is to assist users of water data in the identification, location, and acquisition of needed data. These members are linked so that their water-data holding may be readily exchanged for maximum use. A central Program Office (located in the Water Resources Division of the U.S. Geological Survey) coordinates this linkage and provides overall management of the program. NAWDEX services are also available through a nationwide network of local Assistance Centers."

"The function of NAWDEX is not to become a repository of water data. Instead, the Program Office indexes the data held by NAWDEX members and participants to provide a central source of water-data information available from a large number of organizations. These data may be in both computerized and noncomputerized form."

"NAWDEX has extensive information available that identifies organizations that are sources of water data. This information is provided through a computerized Water Data Sources Directory maintained in the U.S. Geological Survey's computer system in Reston, VA, and is accessible by most Local Assistance Centers via computer terminals."

"The Water Data Sources Directory identifies organizations that collect water data, locations within these organizations from which water data may be obtained, alternate sources from which an organization's water data may be obtained, the geographic areas in which an organization collects water data, and the types of water data collected and available. Information has been compiled for more than 400 organizations, and information on other organizations will be added on a continuing basis."

"NAWDEX, through its Master Water Data Index, provides a nationwide indexing service. This computerized index initially identifies more than 180,000 sites for which water data are availabl from over 300 organizations, the geographic location of these sites, the data-collecting organization, the types of data available, the periods of time for which data are available, the major water-data parameters for which data ar available, the frequency of measurement of the parameters, and the media in whih the data are stored. Information on additional sites will be added on a contiuing basis."

"The Master Water Data Index is alo maintained in the U.S. Geological Surves computer system in Reston, VA, and is acessible by most Local Assistance Centes (see App. A) via computer terminals" (U.S. Geological Survey, 1978, NAWDEX: Key to Finding Water Data. p. 2-10).

US-811

"Federal-Site Survey", U.S. Department of the Interior, Heritage, Conservation ar Recreation Service, Washington, DC 2020

A participation survey was conducted in the summer of 1977 on selected Federal recreation sites, including areas managed by the Forest Service, National Park Service, Bureau of Land Management, Fish and Wildlife Service and the Army Corps of Engineers. Survey questions dealt with their outdoor recreation activities, socioeconomic characteristics and other relevant attributes. Plans are to publish the survey results in the future and for similar Federal-site surveys to be taken every two to three years.

US-812

Range Management System, U.S. Department of Agriculture, Forest Service, Range Management Division, P.O. Box 2417, Washington, DC 20013

This system provides national, regional and national forest level information that is useful for individuals interested in the range resource and the livestock industry. The system's major data elements are forage acres resource forage types, grazing permits and actual grazing used. Annual Grazing Statistical Report, Use Summary (US-514) is a product

this system.

US-813

nge Management Automated System, U.S. partment of the Interior, Bureau of nd Management, Range Division, 18th d C Streets, Washington, DC 20240

This system has information on the reau of Land Management's range man-ement program. Data to the district vel is available on request. Data cat-ories include animal unit months, num-r of grazing animals, numbers of ases, and grazing receipts. Much of is information, to the state level, is blished in Public Land Statistics S-530).

US-814

S. Department of Commerce, National imatic Center, Federal Bldg., Ashe-lle, NC 28801

The National Climatic Center collects tremendous amount of climatic data for e whole country. Many of the data are blished at regular intervals in a se-es of publications. The following se-es are of particular interest:

Local Climatological Data (LCD) is sued monthly and annually for each of proximately 300 National Weather Serv-e stations. The monthly issue includes ily and monthly temperature data, dew int, heating and cooling degree days, ather, precipitation, snowfall, pres-re, wind, sunshine, and sky cover. ree-hourly weather observations and urly precipitation data are also pre-nted for most stations. The annual sue summarizes (monthly and annually) ta for the same 300 stations. Included so is a climatological narrative, a ormals, Means and Extremes" table, and bles listing by month, year, or season erage temperature, total precipitation, tal snowfall, and heating and cooling gree days for approximately the last -40 years.

Climatological Data (CD) is a monthly d annual publication issued for each state or a combination of adjacent states. The monthly issue contains station daily maximum and minimum temperatures, and precipitation. Some stations provide snowfall and snowcover, evaporation, and soil temperature data. A monthly summary is also presented. In addition, the July issue contains a recap of monthly heating degree days and snow data for the past season (July through June). The annual issue contains monthly and annual average temperatures, total precipitation, temperature extremes, freeze data, soil temperatures, and evaporation.

Climatological Data, National Summary (CDNS) is a monthly and annual publication containing data for all National Weather Service (NWS) stations on a nationwide basis. The monthly issue contains mean or total values of pressure, temperature, precipitation, wind, heating and cooling degree days, selected solar radiation data, dew point, relative humidity, sky cover, and sunshine information. Also included are extreme temperatures and precipitation, a storm summary, floodstage data by state, a narrative summary on general weather conditions, hurricanes and national flood events, mean monthly rawinsonde data for all NWS rawinsonde stations, and other selected information. The annual issue presents summaries of all the above data (except pressure) and also includes information on maximum short duration precipitation; a "Normals, Means, and Extremes" table; and a detailed tornado and tropical cyclone summary.

Hourly Precipitation Data (HPD). Issued monthly and annually for each state (or a combination of adjacent states) except Alaska. Hourly and daily precipitation values are presented for stations equipped with recording gages. The annual issue contains monthly and annual totals of precipitation.

US-815

U.S. Department of Agriculture, Forest Service. Washington, DC Office, Regional Offices and National Forest Offices.

The Forest Service, as described in

its "Management Information Handbook (MIH)," has established standard definitions to be used by all levels of the agency in planning and management. A hierarchy of the definitions permits detailed data to be aggregated into more generalized units for decisionmaking at successively higher levels of the organization; that is, data are available on forest, regional and national levels.

Two chapters of the MIH are relevant to this compilation of data sources. The "Activities" chapter contains codes, organizational definitions, and units of measure for Activities and Activity Types Conducted by the Forest Service. The "Outputs" chapter "contains the codes, organizational definitions, and unit of measure for outputs. An output is defined as: goods, end products, or services that are purchased, consumed or utilized directly by people." All data collected by the various units of the Forest Service are available on request. Depending on the level of data needed, National Forest Offices, Regional Offices or the Washington, D.C. Office should be contacted.

COMPUTER TAPES

US-901

Census of Transportation: National Travel Survey. U.S. Department of Commerce, Bureau of the Census, Washington, DC 20233

Part of the Census of Transportation, taken for years ending in "2" and "7", this tape is an extensive survey of travel activity in the U.S. during the census year. Published reports are also available (see US-587).

US-902

Migration Patterns. U.S. Department of Commerce, Bureau of Economic Analysis, Washington, DC 20230

This file, updated annually, has data on characteristics and migration patterns of social security covered workforce for counties and groups of counties. Workforce data is available by sex, race, age, industry and wage class (see also US-592).

US-903

Employment by Type and Broad Industrial Source. U.S. Department of Commerce, Bureau of Economic Analysis, Washington, DC 20230

This file, updated annually, has data on the number of proprietors and full- and part-time wage and salary employees by major industries for states, counties, and SMSAs.

US-904

Personal Income by Major Source. U.S. Department of Commerce, Bureau of Economic Analysis, Washington, DC 20230

Data on personal income by type of income and by major industries, population, and per capita income for states, counties, and SMSAs. This file is updated annually.

US-905

"Input-Output Data," U.S. Department of Commerce, Bureau of Economic Analysis, Washington, DC 20230

Computer tapes with input-output data are available. See US-594 for input-output information available from the Bureau of Economic Analysis.

US-906

Index to 1970 Census Summary Tapes. U.S. Department of Commerce, Bureau of the Census, Washington, DC 20233

"This is a reference guide designed to facilitate easier use of 1970 census summary tape documentation. It is an exhaustive index to census tables organized alphabetically by subject variable." See also Index to Selected 1970 Census Reports (US-604).

US-907

Census of Mineral Industries. U.S. Department of Commerce, Bureau of the Census, Washington, DC 20233

The Census of Mineral Industries is ailable on computer tape and provides ta on the number of establishments, em- oyment, shipments and other relevant formation. The Census is taken in ars ending in "2" and "7" and is also ailable in published form (US-614).

US-908

nsus of Wholesale Trade. U.S. Depart- nt of Commerce, Bureau of the Census, shington, DC 20233

The Census of Wholesale Trade is ailable on computer tape and provides ta on the number of establishments, em- oyment, type of operation, inventories d other relevant information. The Cen- s is taken in years ending in "2" and " and is also available in published rm (US-621).

US-909

nsus of Retail Trade. U.S. Department Commerce, Bureau of the Census, Wash- gton, DC 20233

The Census of Retail Trade is avail- le on computer tape and provides data the number of establishments, employ- nt, sales and other relevant infor- tion. The Census is taken in years ding in "2" and "7" and is also avail- le in published form (US-622).

tah State Government

UT-501

ah Agricultural Statistics. Utah State partment of Agriculture, 147 North 200 st, Salt Lake City, UT 84103

(Issued cooperatively with the U.S. partment of Agriculture, Utah Crop and vestock Reporting Service, P.O. Box 486, Salt Lake City, UT 84147.)

Annual publication presenting major ricultural statistics, including live- ock numbers, production, and prices. so contains a list of reports issued gularly during the year by the Utah Crop and Livestock Reporting Service, including the monthly Livestock Slaughter, the annual Cattle Inventory and Calf Crop, and the annual Sheep Inventory and Lamb Crop.

UT-502

Annual Report. Utah Department of Employment Security, P.O. Box 11249, Salt Lake City, UT 84147

This annual report presents summary data on employment and payroll wages for counties in Utah. Additional information is available on request.

UT-801

State of Utah Department of Natural Resources, Section of Forestry and Fire Control, 1596 West North Temple St., Salt Lake City, UT 84116

Unpublished data available upon request on timber harvests on State lands and State timber sales.

UT-802

State of Utah Department of Natural Resources, Division of Parks and Recreation, 1596 West North Temple, Salt Lake City, UT 84116

Unpublished data available upon request on visitor usage of Utah State parks. This data is also published periodically in the Division of Parks and Recreation publication, Pow Wow.

UT-803

State of Utah Department of Natural Resources, Division of Wildlife Resources, 1596 West North Temple, Salt Lake City, UT 84116

The Utah Division of Wildlife Resources collects numerous types of data that are available on request. Various reports have harvest information, data on license sales and revenues, number of hunting and fishing days, and population estimates. Reports include:

1) Utah Big Game Investigations and Management Recommendations

(issued annually)

2) Utah Big Game Harvest (issued annually)

3) Public Opinion Survey of Fishing and Hunting Activities in Utah. 1976.

4) Biennial Report

Washington State Government

WA-501

State of Washington: Pocket Data Book. State of Washington, Office of Financial Management, Olympia, WA 98504

This annual publication contains statistics and trends concerning Washington and its government. It is divided into statewide information, county information, and cities and towns information. Much of the data is presented in graphical form, facilitating analyses of trends; however natural resource data is limited. A source list suggests sources of further information on the subjects covered in this book.

WA-502

Timber Harvest Report. State of Washington Department of Natural Resources, Olympia, WA 98504

Annual report on timber harvest in the State of Washington. Volume and acreage data are shown by major species and ownership.

WA-503

Washington Forest Industries. State of Washington, Department of Natural Resources, Olympia, WA 98504

Annual report presenting information on the timber industry in Washington, including a comparison with neighboring states and the United States. Prior to 1978 this report was issued quarterly.

WA-504

Washington Statewide Comprehensive Outdoor Recreation and Open Space Plan. State of Washington, Interagency Committee for Outdoor Recreation, 4800 Capitol Blvd., Tumwater, WA 98504

Outdoor recreation plan for Washington, updated approximately every fifth year, containing an evaluation of the demand for and supply of outdoor recreation resources and facilities in Washington, and a program for the implementation of the plan. Supplementary documents are also issued dealing with use data of recreation facilities. This plan is required by the Land and Water Conservation Fund Act of 1965 (Public Law 88-578). At this writing, a revised plan is expected to be issued in 1979.

WA-505

Washington Mill Survey: Wood Consumption and Mill Characteristics. State of Washington, Department of National Resources, Olympia, WA 98504

"This (biennial) report presents comprehensive statistics on wood consumption and the characteristics of primary wood processing mills operating in Washington State. It documents the findings of biennial surveys regarding mill characteristics, wood flow and the input of raw materials into the State's wood-using industries."

WA-506

Washington Forest Productivity Study: Phase I, Report. 1975. State of Washington, Department of Natural Resources, Olympia, WA 98504

"This report provides timber harvest projections for all commercial forest lands in the State of Washington. Projections of timber harvest over twelve decades (beginning in 1975) were made for both Eastern and Western Washington, by ownership group. These projections were based upon the biological potential of the timber resource under varying levels of management intensity without direct regard for economic and administrative constraints."

WA-507

shington Forest Productivity Study: ase II, Economic Analysis. 1977. vid Larsen. State of Washington Department of Natural Resources, Olympia, 98504

"This report provides an economic aluation of sustainable harvest projections identified in Phase I of the shington Forest Productivity Study (A-506). The timber resource was evalted separately for Western Washington nifers, Western Washington hardwoods d Eastern Washington. Further, the aluation was done by ownership. The nd Expectation Value (Faustmann formla) approach was used for selecting tween management intensities for the stern Washington conifers. Management ternatives determined using Land Expecttion Values were compared with the urrent" and "Intensive '75" options om Phase I of the Washington Forest oductivity Study. The sustainable harst projections and present net worth lues indicate possible occurrences for ecified assumptions. By comparing been the various alternatives, an indiction of the range of sustainable harst levels and the related present net rths is provided."

WA-508

shington Agricultural Statistics. shington Department of Agriculture, 406 neral Administration Bldg., Olympia, WA 504

(Issued cooperatively with the U.S. partment of Agriculture, Washington op and Livestock Reporting Service, 9 First Ave., Seattle, WA 98174.)

Annual publication presenting major ricultural statistics, including liveock numbers, production and prices.

WA-509

shington State Sport Catch Report. shington Department of Fisheries, 115 neral Administration Bldg., Olympia, 98504

This annual report contains detailed ta on the sport fish catch for those species that by state law can be harvested commercially. The Department of Game, Division of Fishery Management, is responsible for fish that are caught for sport only. See also WA-802.

WA-510

Income from Management of State Forest Board Lands. State of Washington Department of Natural Resources, Olympia, WA 98504

This annual report presents summary data on income to counties from sales of forest products from State Forest Board Lands and leasing contracts of these lands.

WA-511

Employment and Payrolls in Washington State By County and By Industry. Washington Employment Security Department, Olympia, WA 98504

This publication, issued quarterly, is a compilation of covered employment and payroll data by industry and county. Classification of data by industry is by Standard Industrial Classification.

WA-801

Washington State Parks and Recreation Commission, 7150 Clearwater Lane, Olympia, WA 98504

Unpublished recreation data available upon request. At this writing, monthly state park attendance data are collected, including numbers of day visitors and campers.

WA-802

Washington Department of Game, 600 N. Capitol Way, Olympia, WA 98504

The Washington Department of Game collects numerous types of data that are available on request. Various reports contain harvest information, sport fish catch, data on license sales and revenues, wildlife recreation trends, and population surveys. The Department of Game, Division of Fishery Management, is

responsible for fish that are caught for sport only. The Department of Fisheries is responsible for those species that by state law can be harvested commercially and for sport (see WA-509).

WA-803

State of Washington Department of Natural Resources, Division of Timber Sales, Olympia, WA 98504.

The Division of Timber Sales prepares several internal reports that are available on request. They include:

1) "Preliminary Return on Timber Sales"--Monthly

2) "State of Washington Advertised Timber Sales" (Appraised at more than $10,000)--Quarterly

3) "Summary of Direct Sales" (Sold for less than $500)--Semiannual

4) "Summary of District Sales of Forest Products" (Appraised at less than $10,000)--Semiannual

5) "Timber Sales Activity Cost Breakdown"--Fiscal Year

6) "Closed Scale Sales"--Fiscal Year

7) "Cull Removed"--Fiscal Year

8) "Twenty Top Buyers"--Annual

9) "Summary of Timber Sold, Prepared and Removed"--Semiannual

Wyoming State Government

WY-501

Wyoming Data Handbook. State of Wyoming, Department of Administration and Fiscal Control, Division of Research and Statistics, Cheyenne, WY 82001

Demographic, economic and physical data concerning Wyoming are compiled in this biennial publication. A section with county information complement the State data. An appendix lists all contributors and sources.

WY-502

Visitor Usage Statistics of Wyoming State Parks and Historic Sites. Wyoming Recreation Commission, Cheyenne, WY 82002

Annual compilation of use data in Wyoming State Parks and Historic Sites and selected socioeconomic characteristics of visitors.

WY-503

Wyoming Agricultural Statistics. Wyoming Department of Agriculture, 2219 Carey Ave., Cheyenne, WY 82002

(Issued cooperatively with the University of Wyoming, College of Agriculture and the U.S. Department of Agriculture, Wyoming Crop and Livestock Reporting Service, Box 1148, Cheyenne, WY 82001.

Annual publication presenting major agricultural statistics, including livestock numbers and production, and prices. Also contains a list of reports issued regularly during the year by the Wyoming Crop and Livestock Reporting Service, including the semiannual Cattle Inventory and Calf Crop, the semiannual Sheep Inventory and Lamb Crop, and the monthly Livestock Slaughter.

WY-504

Wyoming Mineral Yearbook. Wyoming State Department of Economic Planning and Development, Mineral Division Barrett Bldg., Cheyenne, WY 82002

Annual report on Wyoming mineral production and valuation. Publication includes sections on each Wyoming county and a mineral commodities review.

WY-505

An Outdoor Recreation Plan for Wyoming. Wyoming Recreation Commission, 604 East 25th, Cheyenne, WY 42002

Outdoor recreation plan for Wyoming updated approximately every fifth year,

taining an evaluation of the demand and supply of outdoor recreation re-rces and facilities in Wyoming and a gram for the implementation of the n. This plan is required by the Land Water Conservation Fund Act of 1965 blic Law 88-578) and was last revised, of this writing, for 1975.

WY-506

te of Wyoming: Annual Report of the artment of Public Lands and Farm ns. State of Wyoming Department of lic Lands and Farm Loans, Cheyenne, 82002

Annual report of the Department of lic Lands and Farm Loans presenting eral data on Department activities, luding grazing and mineral leases, and mary information from the Forestry ision. Some additional information is ilable on request.

WY-507

te and County Summary of Covered Em-yment and Total Payrolls by Industry. loyment Security Commission of ming, Research and Analysis Section, . Box 2760, Casper, WY 82602

This publication, issued quarterly, a compilation of covered employment payroll data by industry and county. ssification of data by industry is by ndard Industrial Classification.

WY-801

ming Game and Fish Department, 5400 hop Blvd., Cheyenne, WY 82002

The Wyoming Game and Fish Department lects numerous types of data that are ilable on request. The following are ng the reports issued:

1) Annual Report of Big Game Harvest
"This report contains the results of harvest surveys (that are) completed following the big and trophy game hunting seasons. Harvest and hunting activity estimates for all big game and black bear were obtained by sampling licensed hunters with mailed questionnaires." Data are presented by management area.

2) Annual Report of Upland Game Harvest
"This report contains the results of harvest surveys (that are) completed following the Upland Game hunting seasons. Harvest and hunting activity estimates for all small game, game birds and waterfowl were obtained by sampling licensed hunters with mailed questionnaires." Data are presented by county.

3) Hunting and Fishing Expenditure Values and Participation Preferences in Wyoming, 1975. 1977. Clynn Phillips and Sheryl Ferguson.
This study was prepared for the Game and Fish Department by the Water Resources Research Institute at the University of Wyoming. The study estimates the amount of money spent on 1975 hunting and fishing activities in Wyoming; conducts an "attitudinal survey of selected resident licensed hunting groups and resident fishermen; (and conducts) a cross-sectional survey of Wyoming households to determine the proportion of the population that participated in various hunting and fishing activities." Similar surveys have been conducted at five-year intervals since 1955. Future plans are to conduct this survey every three years.

ADDITIONAL SOURCES

American Statistics Index (ASI). Congressional Information Service, Inc. 7101 Wisconsin Ave., Washington, D.C. 20014

ASI, issued monthly and annually, "aims to be a master guide and index to all the statistical publications of the U.S. Governement. Specifically, the purpose of ASI is to perform the following functions, promptly and comprehensively:

1) Identify the statistical data published by all branches and agencies of the Federal Government.

2) Catalog the publications in which these data appear, providing full bibliographic information about each publication.

3) Announce new publications as they appear.

4) Describe the contents of these publications fully.

5) Index this information in full subject detail.

6) Micropublish virtually all the publications covered by ASI, thereby providing, on a continuing basis, reliable access to the statistics themselves."

To maximize the usefulness of ASI, the user guide should be examined before searching for the data sources. Numerous libraries throughout the country subscribe to the ASI microfiche.

Bibliography of Investment Costs, Operating Costs and Related Economic Information For the Mineral Industries, January-December (Year). U.S. Department of Energy, Engineering Economics and Standards, Process Evaluation Office, Morgantown, WV 26505.

"This (annual) report contains abstracts of articles concerning different phases of cost engineering and economics for chemical and petroleum plants and mining and other mineral industries. Prior to 1977, bibliographies were issue annually by the Bureau of Mines."

California Environmental Directory: A Guide to Organizations and Resources. Center for California Public Affairs, P.O. Box 30, Claremont, CA 91711

A directory, published every two or three years, listing agencies and private groups which have offices or chapters in California, and are concerned with the environment and related problems.

Conservation Directory. The National Wildlife Federation, 1412 Sixteenth St. N.W., Washington, DC 20036

"The Conservation Directory, revised annually, provides an extensive list of government agencies, organizations, and people active in the conservation field and concerned with natural resource use and management.

Council of Planning Librarians, P.O. Box 229, Monticello, IL 61856

The Council of Planning Librarians issues an extensive series of bibliographies on a multitude of subjects. Many of the bibliographies may be useful for wildland planning and management, including those listed below:

Basic Economic Statistics. 1976. No. 971.

Construction, Housing and Real Estate Statistics. 1976. No. 997.

Energy Statistics: A Guide to Sources. 1976. No. 1065.

Estimating Recreation Benefits: A Critical Review and Bibliography. 1977. No. 1219.

Energy Statistics: An Update to No.

1065. 1977. No. 1247.

Land Planning in National Parks and Forests: A Selective Bibliography. 1977. No. 1291-1292.

Impacts of Outdoor Recreation on the Environment. 1977. No. 1363.

Rural Population Trends: A Survey. 1977. No. 1373.

Forest Environmental Resource Planning: A Selective Bibliography and Guide to the Literature. 1977. 1388-1389-1390.

Wilderness Preservation, Planning and Management: An Annotated Bibliography. 1978. No. 1516.

A Selected Bibliography for Park and Recreation Planners. 1978. No. 1558.

ectory of Computerized Data Files, tware and Related Technical Reports. . Department of Commerce, National hnical Information Service, 5285 Port al Road, Springfield, VA 22161. ailable through NTIS)

"This document contains the bibliophic data of hundreds of computer proms, models and systems generated by or er the auspices of numerous departts, bureaus, divisions and offices in Federal Government. It also contains ortant data bases that are the results Federal Government research and development in a wide range of fields of inest. It contains a subject index, a erating agency index and a number in for easy use in finding needed items" S. Department of Commerce, National hnical Information Service. 1976. ernment reports annoucements: volume 17. p. 102). This publication will updated as future volume makes it nomically feasible. This is also ilable on computer tape.

Directory of Fee Based Information vices. Information Alternative, P.O. 657, Woodstock, NY 12498

"Annually revised listing of information brokers, freelance librarians, independent information specialists, public and institutional libraries and others who provide information for a fee."

Directory of Idaho Information Sources. 1977. Planning Bureau, Division of Budget, Policy Planning and Coordination, Statehouse, Boise, ID 83720

"This directory is a listing of sources of various kinds of information. Its purpose is to help people find the data and information they need for planning and decision making."

Directory of Land Related Data Sources: State Agencies. 1973. State of California, Office of Planning and Research, 1400 Tenth St., Sacramento, CA 95814

This directory identifies the types of land-related data collected by California State agencies and how and where the data may be obtained.

Directory of the Forest Products Industry. Miller Freeman Publications, Inc. 500 Howard St., San Francisco, CA 94105

Issued annually, this is a "reference source for the North American forest products industry--providing detailed information on sawmills, logging operations, plywood and board mills, lumber wholesalers and jobbers in the United States and Canada."

Environmental Data Center. State of California, Office of Planning and Research, 1400 Tenth St., Sacramento, CA 95814

The purpose of the California Environmental Data Center is to develop a comprehensive indexing and reference service for land use and natural resources information collected at the local, state and federal levels. At this writing, the Environmental Data Center is in the process of inventorying existing data resources and in the future will co-

ordinate new data gathering and management efforts.

Federal Energy Data System (FEDS) Technical Documentations. 1978. U.S. Department of Energy, Energy Information Administration, Division of Consumption Data Studies, Washington, D.C. 20461

"This report is a detailed documentation of the Federal Energy Data System, referred to as "FEDS". Some of the more noteworthy features included in this volume are: (1) an explicit definition of each data series including source, methodology, naming conventions, and idiosyncrasies which do not follow directly from the published source; (2) table of contents and description for the on-line FEDS; (3) an explicit detailed description of the FEDS computer tape; (4) completed summary of conversion factors and scalers; (5) glossary of energy terms." See also US-630.

Federal Information Sources and Systems. General Accounting Office, 441 G St. N.W., Washington, DC 20548

This publication is part of the annual Congressional Sourcebook Series, which also includes Requirements for Recurring Reports to the Congress and Federal Program Evaluations. It describes information sources and systems maintained by executive agencies of the Federal Government. There is a description of each system, including the purpose of the system, its output and availability, as well as subject, title and agency indixes.

Federal Statistical Directory. Statistical Policy Division, Office of Management and Budget, Executive Office of the President, Executive Office Building, 17th and Pennsylvania Ave. N.W., Washington, DC 20503.

This biennial, companion publication to Statistical Services of the United States Government, "lists by organizational units within each agency, the names, office addresses, and telephone numbers of key persons engaged in statistical programs and related activites of agencies in the executive branch of the Federal Government. The Federal Statistical Directory is designed primarily to facilitate communication among the various Federal offices working on statistical programs." In the development of this publication, "each agency was requested to furnish a listing of key professional, technical, and administrative personnel engaged in statistical activities such as the following:

1) Planning and operation of general purpose data collection programs.

2) Planning and evaluation of statistical systems, including data processing and progress reporting.

3) Publication and dissemination of general-purpose statistical information.

4) Development and application of statistical methods.

5) Analysis and research which make extensive use of statistical data and methodology including program planning and related activites.

6) Responsibility for clearance of report forms under the Federal Reports Act of 1945 as amended."

Fish and Wildlife Reference Service, Building 1, 3840 York St., Denver, CO 80205

This information retrieval system selectively covers the published and unpublished research reports resulting from the Federal Aid in Fish and Wildlife Restoration program (Pittman-Robertson and Dingell-Johnson Acts), the Anadromous Sport Fish Conservation program, and the Cooperative Fish and Wildlife Research Units. Many items in the system's data base have useful economic data for wildland planning, expecially reports issued by state fish and game departments. Literature searches are available; however fee is charged except for those receivin funding under the Federal Aid in Fish an Wildlife Restoration programs, and the

rdromous Fish Conservation program. h Denver Public Library operates this evice under a contract with the U.S ih and Wildlife Service. The Service lo issues a quarterly newsletter.

cest Resource Data Catalog. 1975. rgon State Department of Forestry, 60 State St., Salem, OR 97310

This catalog is a listing of avail-te sources of forest and forest-related nformation in Oregon. It has been in-eed under three broad headings: the eource measured, the broad geographic plicability of the data and the speci-i ownership class of the data. Sources r from the Federal government, the Ore-c State government, regional and county cernments, and private organizations. h catalog was prepared by Moreland/ nuh/Smith Architects and Planners.

uide to Federal Data Sources on Manu-aturing. 1977. U.S. Department of cmerce, Domestic and International uiness Administration, Washington, DC 030

This guide provides "the user of eeral statistics a framework in which cevaluate the numerous statistics on h manufacturing sector. It attempts:

1. to show the basic types of data available in each publication and

2. the timeliness and detail of the statistics

3. to point up significant differ-ences between statistics from differ-ent sources or surveys

4. to provide selectively definitions for those chapters where the defini-tions contribute to understanding the significance of the data type in-cluded in a specific publication."

ide to U.S. Government Statistics. 93. Documents Index, Box 195, McLean, 7 22101

Last issued in 1973, with no plans for a new edition, this publication "provides an annotated guide to over 1,700 recurring U.S. Government publications from 1-page releases to huge compilations of historical data. In addition the Guide also contains a complete listing of over 3,200 titles in the major statistical numbered series." In many situations this publication has become dated; however it is a good source for historical data.

Information Sources: The Membership Directory of the Information Industry Association. 1977. Information Industry Association, 4720 Montgomery Lane, Suite 904, Bethesda, MD 20014

This publication lists "more than 100 companies which service information needs in virtually all phases of organized activity." The services provided by each company are described.

Monthly Checklist of State Publications. Library of Congress, Exchange and Gift Division, Washington, DC 20540

"The Monthly Checklist of State Publications is a record of State documents issued during the last five years which have been received by the Library of Congress. Monographs are listed each month as they are received and are arranged by State and issuing agency. Included among them are annual publications and monographs in series. The latter are listed as contents under the series title except for publications in college and university bulletin series and similar materials, which are listed under their monographic titles. Periodicals are listed semiannually in the June and December issues, with the December list cumulative for the year. Publications of associations of State officials and of regional organizations and library surveys, studies, manuals and statistical reports appear in two sections at the end of the listing of monographs by State. The value of the Checklist depends in large part on the cooperation extended by State agencies. They are requested to send to the Library of Congress copies of all

their publications and issuances, including materials described above that are not listed."

National Association for State Information Systems Annual Report. National Association For State Information Systems, P.O. Box 11910, Lexington, KY 40578

Annual report of information systems maintained by all state agencies, including a complete inventory and a brief description of all systems. Systems are listed by state and by agency category, including transportation, environment, natural resources, land use, energy, and agriculture.

The National Directory of State Agencies. Information Resources Press, 2100 M St. N.W., Washington, DC 20037

This biennial publication is a compendium of state agencies divided into two parts. The first part lists the 50 states, the District of Columbia and U.S. possessions and identifies all agencies concerned with dozens of functional categories. The second part is organized by these functions and lists the specific agency that is responsible for them in each state, the District of Columbia and U.S. possessions.

Nebraska Natural Resources Data Bank Information System. Nebraska Natural Resources Commission, P.O. Box 94876, Lincoln, NE 68509

This information system was established to aid in resources development, management, and utilization of soil and water resources of the state. Data has been collected from various Federal and state agencies, and the University of Nebraska. All data are available on request. A minimal execution cost is charged to cover the computer use involved in retrieving the information requested.

Profile of Census Programs: Source Documents for Water Resource Planners. 1978 U.S. Department of Defense, U.S. Army Engineer Institute for Water Resources, Kingman Bldg., Fort Belvoir, VA 22060

(This report is a cooperative effort with the U.S. Department of Commerce, Bureau of the Census, Center for Census Use Studies, Washington, DC 20233.)

"This report outlines some of the programs of the Census Bureau that provide data useful for individuals involved in research and planning. The report is divided into six major sections: (1) a general overview of the Bureau's programs and geographic levels; (2) a review of the 1970 decennial census with information on the 1980 and mid-decade censuses; (3) a brief discussion of the economic, agriculture and government recurring censuses; (4) a section concerning surveys; (5) a description of additonal programs, including publications and illustrative examples of maps; and (6) appendixes including addresses and contact persons for summary Tape Processing Centers, Federal and State Cooperative Program for Local Population Estimates, in addition to individual names and telephone numbers of subject matter specialists at the Census Bureau."

Smithsonian Science Information Exchange, Inc., 1730 M St. N.W., Suite 300, Washington, DC 20036

This is a national data base of information on research that is currently in progress throughout the U.S. The information includes research being conducted by all levels of government, major foundations and universities. Research inventories in specific fields are published, some on an annual basis. Searches in other areas can be conducted on request.

South Dakota Land Resource Information System. Planning Information Assistance Section, State Planning Bureau, Carnegie Library Bldg., Pierre, SD 57501

The South Dakota State Planning Bureau has developed the Land Resource In-

ormation System "to assess the present nd potential uses of land within the tate. This information consists of data athered by satellites, high and low altitude aircraft, and ground surveys. The nformation stored in computer data ases, as well as various analysis serices, are available to a broad spectrum f government agencies in South Dakota. he Planning Bureau is cooperating with everal agencies in gathering, analyzng, and converting data into a meaningul form" (Tessar, Paul and Kenneth ansen. The South Dakota Land Resource nformation System).

tatistical Data Reference Service. Data se and Access Laboratories, Suite 900, 501 N. Kent St., Arlington, VA 22209

The Statistical Data Reference Serv-ce (SDRS) sponsored by the National echnical Information Service of the U.S. epartment of Commerce, offers assistance o individuals who have specific data eeds by providing detailed reference information for appropriate data resources esulting from federally sponsored prorams. Publicly available statistical ata files having research and administrative value are emphasized. Regular equests are submitted in writing using he SDRS Request Form (obtainable from DRS) while rush requests may be telehoned directly to the service. Regular equests are processed within five workng days of receipt at a cost of $45.00 er data request. Rush requests are proessed within two working days of receipt t a cost of $75.00 per data request. A eport describing the resource and its ontents is provided for each data source dentified. There is no charge if no ources are identified. An overview of ubject areas covered by SDRS follows:

CRIMINAL JUSTICE STATISTICS:
- Criminal justice system-wide statistical programs
- Crime statistics
- Judicial statistics
- Correctional statistics
- State statistical programs

EDUCATION STATISTICS

ENERGY AND ENERGY-RELATED STATISTICS:
- Exploration and reserves of energy fuel
- Production, supply, and distribution of energy
- Use and consumption of energy
- Financial information

ENVIRONMENTAL STATISTICS:
- Air quality and emissions data
- Water quality and supply
- Radiation data
- Pesticides
- Noise pollution
- Toxic substances
- Solid wastes
- Geologic hazards and other geologic environmental data
- Pollution abatement and control expenditures

HEALTH AND VITAL STATISTICS:
- Health statistics
- Medicare
- Vital statistics

INCOME MAINTENANCE AND WELFARE:
- Social insurance and related programs
- Social and rehabilitation services
- Child welfare
- Vocational rehabilitation
- Other assistance programs
- Proverty statistics

LABOR STATISTICS:
- Labor force
- Nonagricultural employment
- Current and projected industry and occupational employment
- Wages and related practices
- Scientific and technical manpower
- Manpower employment and training

LABOR STATISTICS:
- Productivity estimates
- Labor turnover
- Occupational safety and health
- Work stoppages and collective bargaining
- Health manpower
- Foreign labor statistics

NATIONAL ECONOMIC AND BUSINESS FINANCIAL ACCOUNTS:

Financial reports of business
Capital spending and capacity utilization
Income
Expenditures
Saving
Government transactions
Export and import statistics
Money, credit, and the securities market
National economic accounts

CONSTRUCTION AND HOUSING STATISTICS:
Construction
Housing

POPULATION STATISTICS:
Population counts
Immigration and naturalization
Travel statistics

PRICE STATISTICS AND PRICE INDEXES:
Wholesale prices
Retail prices
Prices paid by farmers
Prices received by farmers
GNP price indexes
International price competitiveness measures

PRODUCTION, DISTRIBUTION, AND SERVICE STATISTICS:
Manufacturing production
Mineral production
Agricultural production
Index of industrial production
Wholesale and retail trade and selected service industries
Marketing of agricultural products
Transportation
Communications
Research and development

Statistical Reporter. U.S. Department of Commerce, Office of Federal Statistical Policy and Standards, Washington, DC 20402

Monthly publication reviewing federal government statistical programs. Regular features include "Current Developments" and "Schedule of Release Dates for Principal Federal Economic Indicators."

Statistical Services of the United States Government. Statistical Policy Division Office of Management and Budget, Executive Office of the President, Executive Office Building, 17th and Pennsylvania Ave. N.W., Washington, DC 20503

This publication, issued very irregularly, "is designed to serve as a basic reference document on the statistical programs of the Federal Government. Part I describes the statistical system of the Federal Government. Part II presents brief descriptions of the principal economic and social statistical series collected by Government agencies. Part III contains a brief statement of the statistical responsibilities of each agency and a list of its principal statistical publications."

USDA Data Base Directory. United States Department of Agriculture, Office of Automated Data Systems, Washington, DC 20250 (This directory is also part of the Forest Service Handbook, FSH 6609.3

This directory is a source of information for automated on-line data maintained by agencies in the Department of Agriculture. The first edition of this directory, issued in 1977, "relates primarily to on-line data maintained by a Data Base Management System." This directory will be merged with a directory on software to be issued by the end of 1979. Thereafter, plans are for annual updates.

What's Published About Colorado. 1978. Business Research Division, Graduate School of Business Administration, University of Colorado, Boulder, CO 80309

This volume is a bibliography of information source publications covering Colorado, its regions, counties, cities and other local areas. The entries are arranged in broad subject groups: Agriculture; Construction, Housing and Real Estate; Development; Economic and Statistical; Education; Labor Force and Employment; Energy; Finance; Government: City, County and Other; Natural Resources; Population and Demography; Tourism and Recreation; Trade and Services; and Transportation and Traffic.

PENDIX: DIRECTORY OF AGENCIES

Federal Agencies

ase note that all listed telephone numbers are commercial.

U.S. Department of Agriculture

Forest Service

Addresses and phone numbers		Areas of responsibility
Washington Office:		
	USDA Forest Service P.O. Box 2417 Washington, D.C. 20013 202-447-3957	Nationwide
Regional Offices:		
Region 1	USDA Forest Service Northern Region Federal Building Missoula, MT 59807 406-329-3011	Montana, northern Idaho, North Dakota and north-western South Dakota
Region 2	USDA Forest Service Rocky Mountain Region 11177 West 8th Avenue P.O. Box 25127 Lakewood, CO 80225 303-234-3711	Colorado, Kansas, Nebraska, most of South Dakota and eastern Wyoming
Region 3	USDA Forest Service Southwestern Region Federal Building 517 Gold Avenue SW Albuquerque, NM 87102 505-766-2401	Arizona and New Mexico
Region 4	USDA Forest Service Intermountain Region 324-25th Street Ogden, UT 84401 801-399-6011	Utah, southern Idaho, western Wyoming and Nevada
Region 5	USDA Forest Service California Region 630 Sansome Street San Francisco, CA 94111 415-556-4310	California and Hawaii
Region 6	USDA Forest Service Pacific Northwest Region 319 SW Pine Street P.O. Box 3623 Portland, OR 97208 503-221-3625	Washington and Oregon

eion 8	USDA Forest Service Southern Region 1720 Peachtree Road N.W. Atlanta, GA 30309 404-881-4177	Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Oklahoma, Texas, Virginia, Tennessee, Puerto Rico, and Virgin Islands.
eion 9	USDA Forest Service Eastern Region 633 West Wisconsin Avenue Milwaukee, WI 53203 414-224-3693	Connecticut, Delaware, Illinois, Iowa, Maine, Indiana, Maryland, New Hampshire, Massachusetts, Michigan, Minnesota, Ohio, Missouri, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, West Virginia, and Wisconsin.
eion 10	USDA Forest Service Alaska Region Federal Office Building P.O. Box 1628 Juneau, AK 99802 907-586-7263	Alaska

Soil Conservation Service

Washington Office:

USDA Soil Conservation Service
Washington, D.C. 20250
202-655-4000

State Offices:

Soil Conservation Service
204 East Fifth Ave.
Anchorage, AK 99501
907-274-7626

Soil Conservation Service
230 N. First Ave.
6029 Federal Bldg.
Phoenix, AZ 85025
602-261-3271

Soil Conservation Service
2828 Chiles Road
Davis, CA 95616
916-758-2200

Soil Conservation Service
P.O. Box 17107
Denver, CO 80217
303-837-3947

Soil Conservation Service
440 Alexander Young Bldg.
Honolulu, HI 96813
808-546-3165

Soil Conservation Service
304 North 8th St.
Boise, ID 83702
208-342-2711

Soil Conservation Service
P.O. Box 970
Bozeman, MT 59715
406-587-5271

Soil Conservation Service
345 Federal Bldg.
Lincoln, NE 68508
402-471-5301

Soil Conservation Service
P.O. Box 4850
Reno, NV 89505
702-784-5304

Soil Conservation Service
P.O. Box 2007
Albuquerque, NM 87103
505-766-2173

Soil Conservation Service
1220 SW Third St.
Portland, OR 97204
503-221-2751

Soil Conservation Service
P.O. Box 1357
Huron, SD 57350
605-352-8651

Soil Conservation Service
125 South State St.
Salt Lake City, UT 84138
801-524-5051

Soil Conservation Service
W. 920 Riverside Ave.
Spokane, WA 99201
509-456-3711

Soil Conservation Service
P.O. Box 2440
Casper, WY 82601
307-265-5550

. Department of the Interior

reau of Land Management

dresses and phone numbers	Areas of responsibility
hington Office: USDI Bureau of Land Management Washington, D.C. 20240 202-343-110	Nationwide
ite Offices: USDI Bureau of Land Management 555 Cordova Street Archorage, AK 99501 907-277-1561	Alaska
USDI Bureau of Land Management 2400 Valley Bank Center Phoenix, AZ 85073 602-261-3873	Arizona
USDI Bureau of Land Management Federal Building Sacramento, CA 95825 916-484-4676	California
USDI Bureau of Land Management Colorado State Bank Bldg. Denver, CO 80202 303-837-4325	Colorado
USDI Bureau of Land Management 7981 Eastern Ave. Silver Spring, MD 20910 301-427-7500	All states bordering on and east of the Mississippi River
USDI Bureau of Land Management Federal Bldg. Boise, ID 83724 208-588-2711	Idaho
USDI Bureau of Land Mangement Granite Tower Bldg. 222 N. 32nd Street P.O. Box 30157 Billings, MT 59107 406-657-6461	Montana, North Dakota, South Dakota
USDI Bureau of Land Mangement Federal Bldg. Reno, NV 89502 702-784-5451	Nevada

USDI Bureau of Land Management Federal Bldg. Santa Fe, NM 87501 505-988-6217	New Mexico, Oklahoma
USDI Bureau of Land Management 729 NE Oregon Street Portland, OR 97208 503-234-4001	Oregon, Washington
USDI Bureau of Land Mangement University Club Bldg. 136 E. South Temple Street Salt Lake City, UT 84111 801-524-5311	Utah
USDI Bureau of Land Management Federal Bldg. Cheyenne, WY 82001 307-778-2326	Wyoming, Kansas, Nebraska

Addresses and phone numbers	Areas of responsibility
Washington Office: USDI Fish and Wildlife Service Washington, D.C. 20240 202-343-5634	Nationwide
Regional Offices: USDI Fish and Wildlife Service Southeast Region 17 Executive Park Dr. NE Atlanta, GA 30329 404-881-4671	Alabama, Arkansas, Flordia, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Puerto Rico, South Carolina, Tennessee, Virgin Islands.
USDI Fish and Wildlife Service Southwest Region P.O. Box 1306 Albuquerque, NM 87103 505-766-2321	Arizona, New Mexico, Oklahoma, Texas
USDI Fish and Wildlife Service Alaska Area 813 D. Street Anchorage, AK 99501 907-265-4864	Alaska
USDI Fish and Wildlife Service Northeast Region One Gateway Center, Suite 700 Newton Corner, MA 02158 617-965-5100	Connecticut, Delaware, Maine, Maryland, New Jersey, New York, New Hampshire, Massachusetts, Pennsylvania, Rhode Island, Vermont, Virginia, West Virginia.
USDI Fish and Wildlife Service Denver Region P.O. Box 25486 Denver Federal Center Denver, CO 80225 303-234-2209	Colorado, Iowa, Kansas, Missouri, Montana, Nebraska, North Dakota, South Dakota, Utah, Wyoming
USDI Fish and Wildlife Service Pacific Region P.O. Box 3737 Portalnd, OR 97208 503-234-3361	California, Hawaii, Idaho, Nevada, Oregon, Washington

USDI Fish and Wildlife Service
North Central Region
Federal Building
Fort Snelling
Twin Cities, MN 55111
612-725-3500

Illinois, Indiana,
Michigan, Minnesota,
Ohio, Wisconsin

ological Survey, Water Resources Division

tional Office:

National Water Data Exchange
U.S. Geological Survey, Water Resources Division
421 National Center
Reston, VA 22092
703-860-6031

Chief Hydrologist (for information on National Water Data Storage and Retrieval System (WATSTØRE))
U.S. Geological Survey
437 National Center
Reston, VA 22092
707-860-6879

strict Offices and Local Assistance Centers:

aska
U.S. Geological Survey
Water Resources Division
218 E. St.
Anchorage, AK 99501
907-277-5526

izona
U.S. Geological Survey
Water Resouces Division
Federal Building
301 West Congress St.
Tucson, AZ 85701
602-792-6671

lifornia
U.S. Geological Survey
Water Resources Division
855 Oak Grove Ave.
Menlo Park, CA 94025
415-323-8111

lorado
U.S. Geological Survey
Water Resources Division
Building 53,
Denver Federal Center
Mail Stop 415, Box 25
Lakewood, CO 80225
303-234-3458

waii
U.S. Geological Survey
Water Resources Division
1833 Kalahaua Ave.
Honolulu, HI 96815
808-955-0251

Idaho
U.S. Geological Survey
Water Resources Division
P.O. Box 036
Room 365, Federal Bldg.
Boise, ID 83724
208-384-1750

Montana
U.S. Geological Survey
Water Resources Division
P.O. Box 1696
421 Federal Bldg.
316 N. Park Ave.
Helena, MT 59601
406-449-5263

Nebraska
U.S. Geological Survey
Water Resources Division
Room 406-Federal Bldg. and U.S. Courthouse
100 Centennial Mall, North
Lincoln, NE 68508
402-471-5082

Nevada
U.S. Geological Survey
Water Resources Division
Room 227, Federal Bldg.
705 North Plaza St.
Carson City, NV 89701
702-882-1388

New Mexico
U.S. Geological Survey
Water Resources Division
P.O. Box 26659
Western Bank Bldg., Room 815
505 Marquette, N.W.
Albuquerque, NM 87125
505-766-2246

Oregon
U.S. Geological Survey
Water Resources Division
P.O. Box 3202
830 N.E. Holladay St.
Portland, OR 97208
503-234-3361

South Dakota
U.S. Geological Survey
Water Resources Division
P.O. Box 1412
Room 308, Federal Bldg.
Huron, SD 57350
605-352-8651

Utah
U.S. Geological Survey
Water Resources Division
8002 Federal Bldg.
125 South State St.
Salt Lake City, UT 84138
801-524-5654

Washington
U.S. Geological Survey
Water Resources Division
Suite 600, 1 Washington Plaza
Tacoma, WA 98402
206-593-6510

Wyoming
U.S. Geological Survey
Water Resources Division
P.O. Box 2087
4020 House Ave.
Cheyenne, WY 82001
307-778-2220

Addresses and phone numbers	Areas of responsibility
Washington Office:	
USDI National Park Service Interior Bldg. Washington, D.C. 20240 202-343-1100	Nationwide
Regional Offices:	
USDI National Park Service North Atlantic Regional Office 150 Causeway Street Boston, MA 02114 617-223-3769	Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey
USDI National Park Service Mid-Atlantic Regional Office 143 South Third Street Philadelphia, PA 19106 215-597-7013	Pennsylvania, Maryland, Delaware, West Virginia, excluding parks assigned to National Capital Region
USDI National Park Service National Capital Regional Office 1100 Ohio Dr. SW Washington, D.C. 20242 202-426-6612	District of Columbia, some units in Maryland, Virginia, West Virginia
USDI National Park Service Southwest Regional Office P.O. Box 728 Santa Fe, NM 87501 505-982-3388	Arkansas, Louisiana, Texas, Oklahoma, New Mexico, northeast corner of Arizona
USDI National Park Service Southeast Regional Office 1895 Phoenix Blvd. Atlanta, GA 30349 404-996-2520	Kentucky, Tennessee, North Carolina, South Carolina, Florida, Mississippi, Alabama, Georgia, Puerto Rico, Virgin Islands
USDI National Park Service Western Regional Office 450 Golden Gate Ave. San Francisco, CA 94102 415-556-4196	California, Nevada, most of Arizona, Hawaii
USDI National Park Service Midwest Regional Office 1709 Jackson Street Omaha, NE 68102 402-221-3431	Ohio, Indiana, Michigan, Kansas, Wisconsin, Illinois, Nebraska, Minnesota, Iowa, Missouri

USDI National Park Service Rocky Mountain Regional Office P.O. Box 25287 Denver, CO 80225 303-234-5000	Montana, North Dakota, Wyoming, Utah, Colorado, South Dakota
USDI National Park Service Pacific Northwest Regional Office Fourth and Pike Building Room 927 1424 Fourth Ave. Seattle, WA 98101 206-442-5565	Idaho, Oregon, Washington, Alaska

B State Agencies

Please note that all listed telephone numbers are commercial.

Agriculture

Alaska
Division of Agriculture
Department of Natural Resources
Sims Bldg.
P.O. Box 1088
Palmer, AK 99645
907-745-3236

Arizona
Commission of Agriculture and Horticulture
1688 W. Adams St., Room 421
Phoenix, AZ 85007
602-271-4373

California
Department of Food and Agriculture
1220 N St.
Sacramento, CA 95814
916-445-7126

Colorado
Department of Agriculture
406 State Services Bldg.
1525 Sherman St.
Denver, CO 80203
303-892-2811

Hawaii
Board of Agriculture
Department of Agriculture
1428 S. King St.
P.O. Box 22159
Honolulu, HI 96822
808-914-3071, Ext. 134

Idaho
Department of Agriculture
4696 Overland Rd.
P.O. Box 790 (83701)
Boise, ID 83720
208-384-3240

Montana
Department of Agriculture
Airport Way Bldg. West
1300 Cedar St.
Helena, MT 59601
406-449-3144

Nebraska
Department of Agriculture
1420 P St.
P.O. Box 94844
Lincoln, NE 68509
402-471-2341

Nevada
Department of Agriculture
350 Capitol Hill Ave.
P.O. Box 11100
Reno, NV 89510
702-784-6401

New Mexico
Department of Agriculture
3190 S. Espina
P.O. Box 3189
Las Cruces, NM 88003
505-646-3007

Oregon
Department of Agriculture
Agriculture Bldg.
635 Capitol St., N.E.
Salem, OR 97310
503-378-4152

South Dakota
Department of Agriculture
Sirgud Anderson Bldg.
Pierre, SD 57501
605-224-3375

Utah
Department of Agriculture
147 N. 2nd West St.
Salt Lake City, UT 84103
801-533-5421

Washington
Department of Agriculture
406 General Administration Bldg.
Olympia, WA 98504
206-753-5050

Wyoming
Department of Agriculture
2219 Carey Ave.
Cheyenne, WY 82002
307-777-7321

lska
Employment Security Division
Department of Labor
P.O. Box 3-7000
Juneau, AK 99811
907-465-2714

rzona
Department of Economic Security
P.O. Box 6123
Phoenix, AZ 85005
602-271-5678

ifornia
Employment Development Department
800 Capitol Mall
Sacramento, CA 95814
916-445-9212

orado
Division of Employment and Training
251 E. 12th Ave.
Denver, CO 80203
303-893-2400

aii
Department of Labor and Industrial Relations
825 Mililani St.
Honolulu, HI 96813
808-548-6468

ho
Department of Employment
317 Main St.
P.O. Box 35
Boise, ID 83707
208-384-2731

tana
Employment Security Division
P.O. Box 1728
Helena, MT 59601
406-449-3662

raska
Division of Employment
550 S. 16th St.
P.O. Box 94600
Lincoln, NE 68509
402-475-8451

Nevada
Employment Security Department
500 E. 3rd St.
Carson City, NV 89713
702-885-4635

New Mexico
Employment Security Commission
401 Broadway NE
P.O. Box 1928
Albuquerque, NM 87103
505-842-3239

Oregon
Employment Division
875 Union St., NE
Salem, OR 97311
503-378-3211

South Dakota
Employment Security Department
607 North Fourth St.
Aberdeen, SD 57401
605-622-2315

Utah
Department of Employment Security
174 Social Hall Ave.
P.O. Box 11249
Salt Lake City, UT 84147
801-533-1433

Washington
Employment Security Department
212 Maple Park
Olympia, WA 98504
206-753-5114

Wyoming
Employment Security Commission
P.O. Box 2760
Casper, WY 82601
307-237-3701

Alaska
Alaska State Energy Office
Office of the Governor
MacKay Bldg.
338 Denali St.
Anchorage, AK 99501
907-272-0527

Division of Minerals and Energy
Management
323 E. 4th Ave.
Anchorage, AK 99501
907-274-8542

Arizona
Minerals and Energy Division
Land Department
1624 W. Adams St.
Phoenix, AZ 85007
602-271-4628

California
Energy Resources Conservation
and Development Commission
1111 Howe Ave.
Sacramento, CA 95825
916-322-3690

Hawaii
Energy Management Unit
Department of Planning and
Economic Development
Kamamalu Bldg.
250 S. King St.
Honolulu, HI 96813
808-548-4080

Idaho
Division of Energy
Office of the Governor
472 W. Washington St.
Boise, ID 83720
208-384-2885

Montana
Energy Planning Division
Department of Natural Resources
and Conservation
32 S. Ewing St.
Helena, MT 59601
406-449-3780

Nevada
Nevada Bureau of Mines and
Geology
University of Nevada
Reno, NV 89557
702-784-6691

New Mexico
Energy and Resources Commission
c/o Governor's Office
State Capital
Santa Fe, NM 87503

Oregon
Department of Energy
528 Collage St., N.E.
Salem, OR 97310
503-378-4128

South Dakota
Office of Energy Policy
Capitol Bldg.
Pierre, SD 57501
605-224-3603

Utah
Interdepartmental Coordinating
Council for Energy Affairs
Department of Natural Resources
438 State Capitol
Salt Lake City, UT 84114
801-533-5356

Washington
State Energy Office
106 Maple Park
Olympia, WA 98504
206-753-4409

Wyoming
Mineral Division
Department of Economic Planning
and Development
Barrett Bldg.
2301 Central Ave.
Cheyenne, WY 82002
307-777-7284

Alaska
Department of Fish and Game
Subport Bldg.
Juneau, AK 99801
907-465-4100

Arizona
Game and Fish Department
2222 W. Greenway Rd.
Phoenix, AZ 85023
602-942-3000

California
Department of Fish and Game
Resources Bldg.
1416 9th St.
Sacramento, CA 95814
916-445-3535

Colorado
Division of Wildlife
Department of Natural Resources
6060 Broadway
Denver, CO 80216
303-825-1192

Hawaii
Division of Fish and Game
Department of Land and Natural Resources
Kalanimoku Bldg.
1151 Punchbowl St.
Honolulu, HI 96813
808-548-4000

Idaho
Idaho Department of Fish and Game
600 S. Walnut St.
P.O. Box 25
Boise, ID 83707
208-384-3771

Montana
Department of Fish and Game
Fish and Game Bldg.
1420 E. 6th Ave.
Helena, MT 59601
406-449-2535

Nebraska
Game and Parks Commission
2200 N. 33rd Street
P.O. Box 30370
Lincoln, NE 68503
402-464-0641

Nevada
Department of Fish and Game
1100 Valley Rd.
P.O. Box 10678
Reno, NV 89510
702-784-6214

New Mexico
Department of Game and Fish
Villagra Bldg.
408 Galisteo St.
Santa Fe, NM 87503
505-827-2923

Oregon
Department of Fish and Wildlife
1634 S.W. Alder St.
P.O. Box 3503
Portland, OR 97208
503-229-5407

South Dakota
Department of Game, Fish and Parks
Sirgud Anderson Bldg.
Pierre, SD 57501
605-224-3387

Utah
Division of Wildlife Resources
Department of Natural Resources
1596 W. North Temple St.
Salt Lake City, UT 84116
801-533-9333

Washington
Department of Fisheries
115 General Administration Bldg.
Olympia, WA 98504
206-753-6623

Department of Game
600 N. Capitol Way
Olympia, WA 98504
206-753-5700

Wyoming
Game and Fish Department
5400 Bishop Blvd.
Cheyenne, WY 82002
307-777-7631

Alaska
Division of Lands
Department of Natural Resources
323 E. 4th Ave.
Anchorage, AK 99501
907-279-5577

Arizona
Division of Forestry
Land Department
3650 S. Lake Mary Rd.
P.O. Box 387
Flagstaff, AZ 86001
602-774-1425

California
Division of Forestry
Department of Conservation
Resources Bldg., 1416 9th St.
Sacramento, CA 95814
916-445-2921

Colorado
State Forest Service
Colorado State University
Fort Collins, CO 80521
303-491-6304

Hawaii
Division of Forestry
Department of Land and Natural Resources
Kalanimoku Bldg.
1151 Punchbowl St.
Honolulu, HI 96813
808-548-5930

Idaho
Forest Resources Division
Department of Lands
Coeur d'Alene, ID 83814
208-664-2171

Montana
Forestry Division
Department of Natural Resources and Conservation
2705 Spurgin Rd.
Missoula, MT 59801
406-728-4300

Nebraska
201 Miller Hall, East Campus
University of Nebraska-Lincoln
Lincoln, NE 68583
402-472-2944

Nevada
Division of Forestry
Department of Conservation and Natural Resources
Nye Bldg., 201 S. Fall St.
Capitol Complex
Carson City, NV 89710
702-885-4350

New Mexico
Department of State Forestry
Land Office Bldg.
Old Santa Fe Trail
P.O. Box 2167
Santa Fe, NM 87501
505-827-2312

Oregon
Forestry Department
2600 State St.
Salem, OR 97310
503-378-2511

South Dakota
Division of Forestry
Department of Game, Fish and Parks
113 Sirgud Anderson Bldg.
Pierre, SD 57501
605-224-3481

Utah
Section of Forestry and Fire Control
Lands Division
Department of Natural Resources
1596 W. North Temple St.
Salt Lake City, UT 84116
801-533-5439

Washington
Division of Forest Land Management
Department of Natural Resources
Lathrop Rd.
Olympia, WA 98504
206-753-5348

Wyoming
Forestry Division
Land Office
Forestry Bldg.
1100 W. 22nd St.
Cheyenne, WY 82002
307-777-7586

aska
Division of Geological and
Geophysical Surveys
Department of Natural Resources
3001 Porcupine Dr.
Anchorage, AK 99501
907-274-8602

Division of Minerals and
Energy Management
323 E. 4th Ave.
Anchorage, AK 99501
907-274-8542

izona
Minerals and Energy Division
Land Department
1624 W. Adams Street
Phoenix, AZ 85007
602-271-4628

Bureau of Mines
University of Arizona
Tucson, AZ 85721
602-884-1943

lifornia
Division of Mines and Geology
Department of Conservation
1416 9th St.
Sacramento, CA 95814
916-445-1923

orado
Division of Mines
Department of Natural Resources
State Centennial Bldg.
1313 Sherman St.
Denver, CO 80203
303-892-3401

Geological Survey
Department of Natural Resources
1313 Sherman St.
Denver, CO 80203
303-892-2611

Hawaii
Division of Water and Land
Development
Department of Land and Natural
Resources
Kalanimoku Bldg.
P.O. Box 373 (96809)
Honolulu, HI 96813
808-548-7533

Idaho
State Bureau of Mines and
Geology
Department of Lands
Moscow, ID 83843
208-885-7991

Montana
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The Forest Service of the U.S. Department of Agriculture

...Conducts forest and range research at more than 75 locations from Puerto Rico to Alaska and Hawaii.

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...Represents the research branch of the Forest Service in California, Hawaii, and the western Pacific.

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Eisenman, Eric, Lee C. Wensel, Edward C. Thor, and Thomas W. Stuart.
1980. *Economic data for wildland management in the Western United States: a source guide*. Gen. Tech. Rep. PSW-42, 125 p. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

This guide identifies and describes sources of economic data useful to wildland managers and planners in the Western United States. The data are categorized by six types of management activities: outdoor recreation and wilderness; wildlife and fish; range; timber; land and water; and minerals and energy. For each type of activity, data sources are identified as to costs; outputs and their monetary values; nonmonetary data and impacts; information for supply and demand analysis; and secondary and indirect effects.

Retrieval Terms: wildland management, outdoor recreation, wilderness recreation, fish management, range management, timber management, land management, mineral lands, water resources, energy, Western United States, economic data, compendia

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Proceedings of Symposium on

Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems

June 22-27, 1980, Riverside, California

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- State of California Air Resources Board

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We are also grateful for the contributions of the Symposium Adviso Committee at all stages of organization. These individuals are Jay H. Blowe and Russel M. Burns, both Man and the Biosphere Program (MAB), U. Department of State; Robert Z. Callaham, C. Eugene Conrad, Jimmie Hickman, and Charles W. Philpot, all of the Station staff; Peter F. Ffollio University of Arizona and MAB 2; Jeffrey B. Froke, National Audub Society; Herb Hahn, Forest Service and Society of American Foresters; Jam N. Pitts, Jr., and O. Clifton Taylor, University of California, Riverside; a Lawrence C. Raniere, U.S. Environmental Protection Agency.

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October 1980

Pceedings of Symposium on

Iffects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems

Jie 22-27, 1980, Riverside, California

l R. Miller
Thnical Coordinator

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REFACE

Sulfur dioxide from fuel combustion and ore smelting operations has caused significant damage to forest communities throughout the industrialized world. In the temperate regions, notably in Europe, the United States, Canada, and Japan, examples of damage and losses resulting from this pollutant are well-documented. Hydrogen fluoride emissions from aluminum reduction plants, brick kilns, and phosphate fertilizer plants also have caused significant damage in many localities. In Mediterranean climates, the combination of abundant sunshine and poorly controlled emissions of nitrogen oxides and hydrocarbons has resulted in extensive forested regions being exposed to photochemical oxidant air pollution. Ozone is the most damaging pollutant in this mixture. Acidic precipitation, derived principally from sulfur oxide emissions, recently has been shown to have severe effects on aquatic ecosystems in northeastern United States, Canada, and northern Europe. The projected increase in the use of coal for energy generation and the continuing growth of urban centers, accompanied by automobile emissions, are two conditions that suggest a continuing and more pervasive influence of air pollution on terrestrial and related aquatic ecosystems.

A large body of knowledge has been assembled that describes pollutant effects on individual species as a result of both field observations and controlled experiments. Efforts are being made to use the tools of systems analysis (modeling) to interpret and predict pollutant effects on processes at both the individual species and plant community levels. The ultimate goal is to improve interpretation of pollutant effects on ecological systems so that optimal protective and management measures can be taken to assure a more healthy environment.

Experimenters and modelers can advance more rapidly if a better exchange of ideas and essential data can be stimulated. A symposium was planned to encourage closer communication between experimentalists carrying out specialized studies of the effects of major air pollutants on individual forest species and researchers using computer simulation models to interpret and predict long-term pollutant effects at the plant community and ecosystem levels. This Symposium, held in Riverside, California, June 22-27, 1980, was designed to report and discuss the state of knowledge of single species-single pollutant relationships, the interactions of producers, consumers, and decomposers under pollutant stress, and the use of ecological systems models for interpretation and prediction of pollutant effects. In addition, the present state of knowledge was examined in relation to an overarching ecological concept: resilience of ecosystems. Another important question was the search for indicators of systems-level effects of air pollution on ecosystems. For example, is an effect on nutrient cycling a reliable indicator of system-level change induced by pollution?

Twenty-eight papers were presented in the formal sessions and 29 poster summaries were displayed concurrently. Registered participants numbered 128. Most participants attended a field trip to the San Bernardino mountains for one-half day. Fifteen nations were represented including Austria, Canada, Czechoslovakia, Denmark, Egypt, West Germany, Japan, Mexico, Norway, Poland, Saudi Arabia, Sweden, Switzerland, United States of America, and Yugoslavia.

To facilitate the publication of the Symposium Proceedings, we decided to have each author assume full responsibility for submitting manuscripts in photo-ready format by the time the conference convened. The views expressed in each paper are those of the author and not necessarily those of the sponsoring organizations. Trade names are used solely for necessary information and do not imply endorsement by the sponsoring organizations.

Paul R. Miller
Forest Service, U.S. Department of Agriculture
Technical Coordinator

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Welcoming Remarks[1]

James N. Pitts, Jr.[2]

Good morning. On behalf of Dr. David Saxon, sident of the University of California, Dr. is Rivera, Chancellor of UCR, and we of the tewide Air Pollution Research Center, I would e to welcome you to this international posium. We trust you will have a scientifi- ly interesting and challenging experience ing this week.

The subject of this meeting is timely and ortant. The accurate assessment of logical, economic, and aesthetic impacts of pollutants on forest ecosystems is essential we are to develop cost-effective control ategies of air pollution. Overcontrol can d to economic penalties in the form of extra ts for expensive technologies for pollutant oval. On the other hand, undercontrol can d to economically unacceptable plant damage ch impacts not only our agricultural and est industry but also our recreational ivities. We trust this symposium will cidate areas of future research that will vide a more extensive data base upon which generate reliable models that can be used for h cost-effective control strategies.

We in California are particularly sensitive the threat, indeed the actuality, of serious pollution damage to crops, forests, etc. iculture remains our number one industry, h tourism and associated recreational ivities also making a major contribution to economic well being of our state.

The fact that the symposium is being held e at UCR seems appropriate since it was a up of plant scientists headed by John Middle- who, in the late 1940s, first showed that nt damage seen in Los Angeles County was in t due to a new type of air pollution. Through their efforts and the pioneering research of the late Arie Haagen-Smit and others, it became clear that we were dealing with an oxidizing atmospheric system formed by the action of sunlight on hydrocarbons and oxides of nitrogen.

During the last twenty years, much of it under the leadership of Clif Taylor, research has been conducted here in two major areas: Studies of pollutant effects on plants, vegetation, and forest ecosystems, and the chemistry of air pollution. This has been a particularly useful combination of interests because we have one group of scientists working on one axis of the classic dose-response curve, that is, the atmospheric chemists whose function is to describe the dose received by man, animals, or plants, and another group working on the response axis, the plant scientists investigating the interactions of air pollutants with vegetation.

Most of you are familiar with the work which has been done here in the plant sciences area. Let me just mention that one of the major roles of the atmospheric chemists at the Center has been the unequivocal spectroscopic identification and measurement of several new gaseous oxygenated and nitrogenous species that are formed in photochemical air pollution. These include formaldehyde, formic acid, nitric acid, nitrous acid, and the nitrate radical, NO_3. Whether or not such gaseous species will prove to be significant phytotoxicants is a question that we leave to you "response" specialists.

In closing I want to thank Drs. Paul Miller and Clif Taylor and Mrs. Neva Friesen for their outstanding efforts in organizing this symposium. Many other people deserve a great deal of credit as well, but there simply is not time to acknowledge them individually. Let me just say that we are pleased to host a meeting of this importance and we look forward to learning of the significant results that will emerge from your gathering. I am certain these results will be of lasting importance to this critical area of the air pollution problem.

[1]Presented at the Symposium on Effects of Air lutants on Mediterranean and Temperate est Ecosystems, June 22-27, 1980, Riverside, ifornia, U.S.A.

[2]Professor of Chemistry and Director, Statewide Pollution Research Center, University of ifornia, Riverside, California.

Opening Remarks[1]

Robert Z. Callaham[2]

My reasons for being here are to welcome you on behalf of the Forest Service, U.S. Department of Agriculture, and to introduce you to this conference. I want to explain to you the objectives of the conference, why it was organized, and who made it possible. But I also want to introduce you to each other, so that you will know which countries you represent, and why you are here.

I will begin by stating the three objectives of this conference. The first is to review current information on specific gaseous and particulate pollutants and their effects on forest ecosystems. Forests as sources of pollutants and as sinks for pollutants are included. The second objective is to analyze primary, secondary, and interactive effects of chronic pollutants on ecosystems. Modeling will be explored as a tool to simulate observed and expected effects. Late in the program, strategies for assessing and managing environmental impacts of air pollutants will be discussed. The third objective is to stimulate international communication to assess the state of knowledge and to identify gaps in our knowledge.

Several years ago, the U.S. Environmental Protection Agency (EPA) gave a grant for research to Dr. Clif Taylor in the Statewide Air Pollution Center here at Riverside. The Forest Service has actively cooperated and participated in the resulting research up to the present time. Research under that grant is drawing to a close. This conference was planned, therefore, to sum up what has been accomplished. Scientists involved in this multimillion dollar research effort have this opportunity to tell others what they have learned and to identify problems that remain to be solve. Another purpose in organizing this conference is to broaden local perspectives by importing expers from around the world to talk about our problems. The final purpose is to transfer technology generated by this research program to the managers f air, land, and forest resources.

This conference was made possible through the cooperative efforts of several agencies. The Forest Service, U.S. Department of Agriculture, and the Statewide Air Pollution Research Center University of California, at Riverside, are spon sors. IUFRO, the International Union of Forest Research Organizations, having about 380 member organizations in 86 countries around the world and a subject group concerned with air pollution, is a cosponsor. The U.S. Department of Energy and the U.S. Environmental Protection Agency have made their people and their resources available. EPA will help the Forest Service to publish the proceedings. The U.S. Department of State, particularly the Man and the Biosphere Program through its Project 2--Mediterranean and Temperate Fore Ecosystems--has provided financial support. UNESCO, the international home of the Man and the Biosphere Program, has paid to bring three international participants here. For all of this support and cooperation, the organizers are most grateful.

My final and, perhaps, unexpected reason f being here is to introduce you to each other. Although this is not often done at conferences, I have found it to be an effective means of stimulating communication. I am going to call the roll of countries, more or less in alphabetical orde and ask the individuals named to stand. (Introductions followed.) About 20 percent of the people here are from outside North America. Let us give these visitors a special welcome. Walk up to them. Introduce yourselves. Ask these visitors about programs and problems in their countries.

Now that we know what countries are represented let me call for a show of hands to find out why

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[1] Presented at the Symposium on Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, June 22-27, 1980, Riverside, California, U.S.A.

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3 of you are here. How many are primarily ehers or professors? About 7 percent. How a are managers of land or forest resources? bt 9 percent. How many are managers of air re-oces? Only about 2 percent. That is surpris-n How many of you are students, not yet into ressional activities? About 2 percent. The einder of you--about 80 percent--are scientists n investigators. That is about what I expected.

And now my role is fulfilled. I have introduced you to the conference and to each other. I expect you to benefit both professionally and personally from this conference. Lastly, I express my deep appreciation to all who have contributed to the organization of this conference and particularly to Dr. Paul Miller.

On behalf of the Forest Service, I thank you for coming. The ultimate success and meaning of this conference depend on you.

Air Pollution in Forests: Social Costs, Predictive Models, and Public Policy[1]

Charles F. Cooper[2]

Abstract: Long time scales, spatial variation in ecosystems, and differing value judgments make models almost essential for societal consensus about air pollution. Three categories of policy-oriented models are described. Empirical time series models are good for immediate decisions but are inherently a short-term device. Detailed structural-functional models emphasize relationships among components and demonstrate the significance of interconnections. Small errors, however, can lead to erroneous quantitative results, limiting their value for direct policy decisions. Aggregated policy-oriented models provide better compliance between model output and validation data at the cost of loss of resolution. Good models should be clearly documented, results should be comprehensible, limits and probable error bands clearly stated, they should be flexible enough to deal with unanticipated problems without attempting total generality, and results should be clearly displayed. A model is an aid to decisionmaking, not a decision maker. For it to be effective in that role, there must be mutually supportive interaction among modelers, biological and social scientists, and decision makers. Perhaps the most significant role of models is in helping to avoid suboptimization and in facilitating communication among disciplines and practitioners.

Atmospheric pollution is affecting forest ecosystems in much of the world. A major purpose of this symposium is to establish a scientific consensus about the nature, magnitude, and time trend of these effects. A scientific resolution, however, is not enough. Analysis of "The Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems" must also take societal objectives and limitations into account.

Ecosystems used and enjoyed by man are embedded in a larger social system; dealing with effects of air pollution on these ecosystems, locally, regionally, or globally, thus becomes a question of public policy. Essential to sound public policy formulation is knowledge of the social costs of air pollution and its control. A major problem, of course, is how to measure these costs. This symposium should lead us some way toward better assessment of the real costs of forest air pollution.

[1]Presented at the Symposium on Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, June 22-27, 1980, Riverside, California, U.S.A.

[2]Professor of Biology and Director of Center for Regional Environmental Studies, San Diego State University, San Diego, California 92182.

The ecological and social consequences of a pollution in forests are the result of compl interactions of processes with many tempora spatial, and value scales. Long-time scale variations among ecosystems, and differences opinion about values make classical laborato experimentation almost useless for defining the large scale consequences. Models are th essential for helping to arrive at a societ consensus about how to treat air pollution.

COMPLEXITY OF THE FOREST AIR POLLUTION PROBL

It is a truism that the forest air polluti problem is complex, but the nature of th complexity must be understood if we are visualize the role of models in dealing with i The points mentioned here are elaborated by oth authors in this volume.

Air pollution affects individual plan directly, in ways which change during the course the plant's life history. It affects plan indirectly, through impacts on soils and consumers and decomposers. Effects on plants, turn, are reflected in other trophic level Critically important is the dynamic reaction ecosystems, which usually cannot be predicted fr a simple summation of the responses of individu organisms.

Social consequences stem from loss productive resources and amenity values. Wood an

orage growth may diminish, a loss that will be ncreasingly significant if forests are in greater emand for biomass as a source of energy or tructured chemicals, or if increasing need for rain as food leads to more pressure on rangelands. esthetic and recreational values are lost. The egraded appearance of the smog-affected forests of he San Gabriel Mountains are apparent to all who ave seen them. Wildlife, both game and non-game, ay suffer. Lakes and streams in several parts of orth America and Europe have lost much of their apacity for fish production (Loucks 1980). Of ourse, there may be beneficial impacts as ell--alleviation of local sulfur deficiencies, for nstance. Both beneficial and detrimental effects ary in time and space.

Air pollution operates at many time scales. olling (1973) has distinguished between fast and low variables. Fast variables are generally nenable to conventional laboratory xperimentation, and are the kind that are usually tudied in biological research. Slow variables, owever, take long enough to manifest themselves hat controlled experimentation is impractical in any real world situations where action cannot ait. Decision makers must also deal with a high egree of spatial heterogeneity in both pollutants nd their target ecosystems. Theory and research n ecology has not until now dealt very well with patial processes.

Finally, air pollution is only one of many tresses affecting forest ecosystems. Multiple tresses may interact synergistically or they may elp to counteract one another. We need to know ore, for instance, about the combined impact of ir pollution and climate change, whether due to eliberate weather modification or inadvertent limatic change. Increased atmospheric carbon ioxide from burning of fossil fuel seems likely to arm the earth's climate and, perhaps, to stimulate lant growth directly. How will these processes nteract with air pollutants? Forest harvest and egeneration is itself a stress on the ecosystem hich will interact with increased pollutant oading. Air pollution in forests thus is part of complex network of biological and social nteractions whose integrated impacts are almost mpossible to untangle through single-factor nalysis.

A SCIENTIFIC APPROACH TO COMPLEXITY

There are some four possible societal esponses to complex problems such as air ollution. We can attempt to treat the symptoms hrough such means as fertilization or irrigation, alleviate the cause through emission control, accept the degradation as gracefully as possible, or convert the affected ecosystem to one more esistant to stress. Actual policy solutions will probably include some combination of these.

How do we go about choosing the appropriate policy response? One way is simply to rely on the judgment, hopefully good, of the people, hopefully experienced, in charge. This is the common procedure. There is, however, a more organized scientific approach to complex problems with many temporal and spatial scales. This process includes eight basic steps.

1. Make a model of the process, based on existing knowledge and understanding of the system. The kinds of model which might be undertaken in this step are discussed in more detail below.

2. Fit the parameters of the model to data, preferably obtained from laboratory or field experimentation; otherwise from observational studies.

3. Validate the model. This involves comparison of model results with real world outcomes in systems other than those used in fitting the parameters. This is a crucial but also a most difficult step, because the objective of the whole modeling exercise is often to predict responses of systems under stresses that exceed the range of existing validation data.

4. Test the sensitivity of the model to parameter changes. This can help to locate critical features where better understanding or more accurate data are needed. It can also help locate parts of the system where relatively small changes may have large effects. Sensitivity analysis is often said to be one of the great virtues of a modeling approach, in that it leads to directing limited resources to areas where they will do the most good, or conversely avoids the expenditure of effort on measures unlikely to have much effect. Points of special sensitivity are often hard to find, however. Both control theory and practical experience are increasingly demonstrating that many complex interlinked systems are relatively insensitive to small changes in one or two variables. This should come as no surprise to those who have observed the evident resilience of ecosystems under stress (Holling 1973). Sensitivity analysis remains, nevertheless, an important application of policy-oriented models.

5. Use the model outside the ranges of stresses previously experienced. One of the pitfalls that all of us have been warned to avoid in science is extrapolation, yet it is just because of the need for extrapolation that models are called for in predicting ecosystem consequences of air pollution. The response of the model system will usually need to be estimated under pollution loads greater than those already experienced by that system. Even more important is the time dimension. A primary goal often is assessment of the long-term consequences of chronic or episodic air pollution. It is just because of this

extended time dimension that models are needed, and yet this is perhaps the most difficult element in their construction.

6. Array the output for public discussion. Since the purpose of the models we are considering here is to help in arriving at some sort of consensus about appropriate societal response, presentation must go beyond the immediate scientific community. Seldom, if ever, will the output of a realistic air pollution model lead to deterministic predictions. Rather, there will be a range of alternative outcomes, each with a probability level attached. It is notoriously difficult to interpret risk probabilities in terms of public attitudes. There is a growing literature on probabilistic risk assessment which is highly pertinent to the air pollution problem (e.g., Kates 1978, Starr and Whipple 1980).

7. Amalgamate with output of other relevant models of societal issues for final public evaluation. Air pollution is only one of many problems facing society. Measures taken to alleviate the consequences of air pollution are likely to ramify into many other aspects of society. In my view, the most important single use of a policy-oriented model is as an aid in avoiding suboptimization. By suboptimization, of course, is meant choosing what is clearly and logically the best solution to a small part of a problem without adequately considering the impact of that solution on the total system. An example of how suboptimization along a narrow path may turn out to be not just slightly wrong, but <u>exactly</u> wrong in a broader context is the disposal of chemical wastes at Love Canal, N.Y. Out-of-sight, out-of-mind burial was a good solution at the time for the potential hazard to workers and the public of this material; its consequences are now affecting all Americans, as taxpayers, if not as recipients of direct chemical insult. Less extreme cases of suboptimization may be more difficult to identify before action is taken. If a properly designed model, by exploring a wider range of alternatives than can the human mind alone, helps to avoid the long-term costs of suboptimization, the effort in its construction will be well rewarded.

8. Move toward a decision. There is no hope that a decision, even if based on the best conceivable model, will satisfy all interested parties in a controversial issue. One could expect, however, that the decision would be more rational than if based on emotion and maximization of each participating individual's personal objectives.

KINDS OF POLICY-ORIENTED MODELS

Models may be merely conceptual and verbal--a intuitive, possibly quite accurate, visualizatio of how the world works. We are concerned here however, with mathematical models able to deal wit interactions among more variables than the unaide human mind can readily handle. These are o several basic kinds, which differ in both thei underlying structure and their range o application. (This section owes much t discussions with W. R. Emanuel, Environmenta Sciences Division, Oak Ridge National Laboratory.

1. Empirical time series analysis. The emphasi here is on analysis of the secular trend o the variables of interest. It is assume that the processes during the period o record will continue over the interval o extrapolation. A time series model need no include explicit casual relationships. I must, however, incorporate sufficient data t establish the statistical significance of th observed patterns. In the words of Denni Meadows (1975), it is "data rich, theor poor."

   Such a time series analysis is often idea for decisions which must be made immediatel but which can be revoked in the light of ne information without lasting damag biological, or political. Time seri analysis has the advantage that it is easil understood by decision makers who are n analytically inclined. It is inherently short-term tool, however. Lack of explic casual relationships makes extrapolation ev more risky than with other models.

2. Detailed structural-functional models. The incorporate the structure and function of t system to the extent that it is known. The is a wide variety of suggested procedures a approaches for constructing such model several are discussed in this volume. T emphasis throughout is on understandi relationships and processes, not trends. Meadows' (1975) words, they are "theory ric data poor."

   Their principal value is as an aid understanding relationships among componen and the significance of interconnection They are often useful for pointing out decision makers why certain relationshi whose importance is not intuitively obvio are actually more significant than they see

   Properly constructed functional models c lead to prediction of ecosystem responses stresses, which are likely to differ marked from those of individual organisms tested isolation. West and others (1980) used model of successional dynamics to test t long-term impact of air pollution on easte deciduous forests. Their model predict

enhanced growth of some species despite pollutant stress, since they may gain a competitive advantage because they are less sensitive than other species with which they interact in the successional process.

Neither ecological models, nor ecological theory in general, deal well with spatial dynamics in forests. Most emphasis has been on successional dynamics over time at a point or in a small area. There have been attempts, as by Shugart and others (1973) to model the "flow" of one form of land use or vegetation condition to another, but this approach is chiefly usable for very large units. Because air pollution is both spatially extended and spatially variable, there is a need to incorporate these features into ecological models of air pollution. A promising approach seems to be the linking of existing forest succession models with cartographic models developed by geographers for dynamic map analysis. Efforts to do this are now underway in several research units. The results should be valuable for air pollution studies.

Despite their great value for many purposes, however, detailed structural-functional models are usually unsuitable for deciding upon specific actions or policies. Small errors, either in theoretical underpinnings or in parameter estimation, can lead to quantitative predictions that turn out to be quite wrong when tested against the limited validation data usually available. We can hope, though, that improvement in both modeling technique and in biological and social knowledge will lead to functional models truly useful as decision tools.

3. Aggregated policy-oriented models. Here, there is an attempt to combine the many structural elements of the system into a relatively few well-understood components for which good cause and effect data exist. The major structural and functional relationships are preserved, but at a lower level of resolution with respect to their interconnections. Full understanding of the complex system is traded for greater computational tractability, and a greater possibility of showing time series data.

With this sort of model in hand, scientists can interact with decision makers in a quantitative way to prepare an array of alternative actions and their probable consequences. Various tools of optimization, an active area of current research, come into play here. Particularly valuable in a problem with as many conflicting value judgments as effects of air pollution may be the multiple objective optimization extensively used in evaluating water resource development alternatives (Cohon and Marks 1975). This is a planning concept which provides a quantitative framework for the task faced by all decision makers, that of achieving an acceptable compromise among a set of competing objective functions. The various analytical techniques used for this purpose agree in using the model to offer tradeoff functions of some kind to the decision maker. But he, not the model or the modeler, establishes priorities among the planning criteria. The model is thus just one more tool for bringing precision into the planning process and for evaluating the consequences of alternative choices.

Ecological policy models would be substantially improved if they could directly incorporate human decision making in response to ecosystem change. Active research is in progress to make this possible. For instance, C. L. Smith, J. M. Stander, and A. V. Tyler (personal communication 1980), of Oregon State University, an anthropologist, an ecosystem modeler, and a fisheries biologist, have collaborated in developing an interactive model of a mythical human hunting and gathering society and an exploited fishery. Human participants are faced with alternatives which force them to make choices. The consequences of the choices are then evaluated by the models in accordance with previously developed decision rules. They found that decision making in simulations did alter model outcomes. Decisionmaking in the fishery simulation led to a stable equilibrium; without it, there was periodic cycling of fishing vessels and fish biomass. Wrong decisions, though, led to extinction--economic extinction of the fishery before biological extinction of the fish. Similar interactive modeling ideas are being developed by Holling (1978) and his associates and followers under the rubric of Adaptive Environment Assessment.

DESIRABLE CHARACTERISTICS OF MODELS

To be effective tools for assisting in policy decisions, models should have several characteristics (Cooper 1976). It is almost totally irrelevant in this context whether the model uses differential or difference equations or whether it is written in FORTRAN or BASIC. There are more fundamental features which determine whether a model is likely to be accepted and used in decisionmaking.

1. It should be extensively and clearly documented. How was the model developed and what are its assumptions? This should be evident, if not to the ultimate user, at least to those who might serve as technical consultants. Unfortunately, this is a serious weakness of most models. This arises partly from funding limitations--documentation is an obvious thing to skimp if the budget has to be cut. I suspect that not infrequently, though, there is a wish, maybe subconscious, to keep what the modeler did to himself. After all, knowledge is power.

2. Its results should be understandable--surprising, perhaps, but not incomprehensible. Forrester (1971), in a widely quoted article, discussed the counterintuitive nature of social systems, and prescribed computer modeling as an antidote. But Forrester was able to explain quite clearly how he obtained his counterintuitive results (others disagree with his analysis, but that is irrelevant here). He would have had no credence whatever if he had not been able to provide such explanation.

3. The limits and probable range of errors should be well explained. Few computer models yield deterministic results, and all are limited in their acceptable degree of extrapolation. This is often not well understood by those not analytically inclined; it needs to be made clear.

4. The model should be flexible enough to deal with problems that had not been fully anticipated, but a general all-purpose model is not a desirable goal. Senator S. I. Hayakawa's dictum, "The map is not the territory," although made in quite another context in his role as a semanticist, is wholly applicable to modeling. A model is a map that tells us how to get from one place to another, even to some places we had not originally intended to visit. It cannot reproduce every feature of the system and still retain its usefulness as a guide.

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6. The model should be portable--usable on other computers with a minimum of reprogramming. I have the feeling that incompatibility has become worse in recent years. This will presumably correct itself eventually, but for now it is a serious problem.

CONCLUSIONS

The impact of air pollution on forests, especially when combined with other stresses, has biological, social, and political implications which operate at several time scales extended over space. The unaided human mind is not well adapted to explore the consequences of each of the large number of possible combinations of variables. Therefore, some sort of computer model is virtually essential if the most reasonable array of alternatives is to be presented for rational choice.

A policy-oriented model is not a decisic maker. It is an aid to informed decisionmaking If it is to function effectively in that role there needs to be mutually supportive interactior among modelers, biological and social scientists and decision makers.

A modeler dealing with ecological publi policy questions related to air pollution i forests needs the knowledge of a biologist, t understand the essence of the mechanisms by whi air pollution affects biological processes. I needs the skills of an applied mathematician, t understand the structure of the model and it implications, and usually to direct the programme preparing the actual computer code. Mos important, he needs the patience and interpersona abilities of a diplomat, to persuade the biologis and the deicison maker alike that he is helpi them to do their job better, and not usurping thei legitimate roles.

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Decision makers should realize that a go model is primarily a means for exploring t consequences of alternative policy choices nearly equal rank. If the model shows one or t choices to be so superior to others that only th should be considered, this will surely be obvio to competent analysts in the absence of a model The real utility of a policy-oriented model is explore those situations where there are a lar number of alternatives which are neither all go nor all bad. The broader the array of choices s up for exploration, the greater the final range opportunities will be.

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Historical Perspectives and International Concerns About Air Pollution Effects on Forests[1]

Edwin Donaubauer[2]

Abstract: Air pollution from man's activities has a long history; real hazards for forest vegetation occurred more than a century ago which marked the starting point of forest research in the field. The objectives of research have been subject to a steady metamorphosis from simple causal relationships to the task of investigating the long-term influence of pollutant mixtures on trees directly and on entire ecosystems. The IUFRO Subject Group S2.09, Air Pollution, encourages interdisciplinary work in the field and offers an organizational home for close cooperation on an international basis. The consideration of air pollution effects on forest ecosystems goes far beyond limited forest interests, the findings can provide fundamental data on the deterioration of the human environment.

Some forest insect pests develop outbreaks characterized by high insect population densities that use up the food resource represented by the host species. The direct damage by insects and the predisposition of weakened trees to certain diseases both result in a serious degradation or even destruction of the local forest environment.

To some extent man-made air pollution problems show some similar aspects. In many regions of the world mankind cleared the forests for agriculture, for settlements, for roads, for mining, for outdoor recreation, etc. Wood is still in high demand as an energy source, and in fact is still the most important source for over 90 percent of the world's population. Collection of fuel wood and the harvesting of timber for many uses have influenced the extension and quality of forests over long periods of prehistoric and historic time. All these activities had, at least in some major regions of the globe, serious consequences for the ecosystem and human environment. We are reminded of the historical fact, that 2000 years ago forests existed around the Mediterranean Sea and protected large and prospering agricultural areas in North Africa, where deserts are now present. These were direct influences, but among others an additional indirect threat developed by the quick progress in technology and by increasing quantities and numbers of toxic substances released into the air.

Certainly, man-made air pollution has been mentioned long ago in historic times, but the dimensions of the problem have changed in relation to regional economic and technical developments. The effects of air pollution to forest ecosystems were and seem still to be underestimated, maybe for these reasons:

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[1]Presented at the Symposium on Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, June 22-27, 1980, Riverside, California, U.S.A.

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symptoms are often unspecific, or develop late and slowly, or are even invisible (as depression of growth increment);

serious changes in forest ecosystems may become obvious only after many years of accumulation of low concentrations or amounts of toxic substances (heavy metals, alkaline dusts, acid rain).

trees are more sensitive to widely distributed pollution than humans and this difference is not fully known or realized.

REMARKS ON HISTORY

Perhaps Pliny (65 A.D.) was the first to oserve and describe apparent SO_2-damage to egetation surrounding a smelter. Later on find references frequently in documents of e Middle Ages concerning air pollution by al burning; in general people of higher soal classes felt inconvenienced. Especially such reports from England and Central rope persecutions happened even at that time air pollution was caused in a prohibited ea or time.

Air pollution became more than a local and casional affair when industrialization and e use of fossil energy resources increased pidly in Western and Central Europe during e past century. By the time forest research stitutes and forest faculties were established - more than a hundred years ago - they d several reports of prior experience and servations of botanists to draw upon. Therere forest research was stimulated to pay attion to air pollution problems from the benning. The present research projects provide merous publications on air pollution effects.

CHANGING AIMS AND TASKS

The objectives of research projects conntrated first on sulphur dioxide including thods for detection and evaluation of air llution damage. Among these early works we nd very forward-looking ones, as Rusnov's 919) study about the influence of 'acid in' (this term was introduced much later) forest soils. Several authors proved the e of chemical analysis of foliage for detction and evaluation of air pollution (SO_2,) and its effects on forest stands. These blications caused long lasting discussions d stimulated further investigations; hower, many years passed until the chemical alysis of foliage (needles) became a useful ol for a great number of cases. Step by ep the method was refined, so that today fficient knowledge is available for proper mpling, and the thresholds of natural sulfur d fluorine contents and their variation are tter defined.

Certainly, sulfur dioxide is still the polant occurring over largest areas, but the st of substances thus far identified as reonsible for damage to forest trees becomes nger and longer. More attention is now given to indirect and chronic effects of acidic or alkaline precipitation and heavy metals on forest ecosystems.

Formerly, the interest of forest research concentrated on a single-pollutant-single-tree species relationship. Today, increased efforts are invested in elucidating the complex influences on forest ecosystems and studying the interaction of pollutant mixtures which occur in many cases.

Regional investigations on air polluted forest zones use all assistance of modern technology, such as remote sensing combined with physiological, chemical and tree mensuration methods for verification.

Forest air pollution problems are linked with the economic standard in general and with certain industrial development.

But it is not necessarily so, that only point sources of air pollution or concentrations of industries cause serious problems. Automobile traffic or even a single source area can under specific orografic and meteorologic conditions lead to pollutant accumulation and perhaps to heavy damage. Further, we are learning more about long distance pollutant transport over hundreds and thousands of kilometers.

The experience in nations with highly developed industry makes it advisable to stimulate more interest in this field of research in many developing countries in the world. First of all the experiences of others should be transmitted and applied in all planning for economic development to avoid the same historical lessons received by many developing countries. There are many forest research workers and institutions in North America, Europe (including the Asiatic part of USSR), and Japan who are experienced with the various aspects of air pollution effects on forest ecosystems and could provide scientific information and assistance.

I U F R O AND AIR POLLUTION RESEARCH

The International Union of Forest Research Organizations (IUFRO) has six major organizational divisions. Division 2, 'Forest Plants and Forest Protection' is home for ten Subject Groups, one of which is S2.09 - 'Air Pollution.' The titles of the various Working Parties elucidate the interdisciplinary scope: Researchers are included from the fields of forest mensuration, soil science, pathology, remote sensing, tree physiology, etc. They work together, and exchange research results that stimulate their further research. This IUFRO Subject Group has a long history of activity. For more than a quarter of a century meetings have brought together an increasing number of participants. A few western and central European countries were represented at first; now more countries from eastern and southern Europe are represented too, as well as a slowly increasing number of participants from Canada and the U.S.A. The eleventh meeting of all Working Parties will

be held this year in Graz, Austria and previous conferences were hosted by nine other European countries. It is somewhat disappointing that the group met only once in another continent: Gainesville, Florida, U.S.A. at the occasion of the IUFRO Congress in 1971. We expect to have a meeting at the occasion of the 1981 IUFRO Congress in Japan.

The interdisciplinary scope of all Subject Group meetings makes them attractive to a certain group, seldom represented at such scientific conferences. We could characterize this group as 'consumers' of research results including: forest managers, representatives from industries, and sometimes politicians. There are of course some difficulties in accommodating the needs of each group, but I consider the interest in such meetings as an expression for a demand to receive the information from the scientists directly and not via more traditional channels, i.e., technical publications. I feel we should think of possibilities for such direct information flow in specific fields like air pollution where we find more and more vital interest from the public.

I feel that this international symposium sets the stage for new conceptualizations by placing the view of effects of air pollutants on forest ecosystems into the center of the deliberation. The discussions here should stimulate further research and interdisciplinary, international cooperation.

In addition I will emphasize that air pollution effects on forests are not only a question for researchers or foresters, but of fundamental interest to mankind. That may seem overstated but forest ecosystems demonstrate due to the long rotation periods the dynamics and the consequences of long-term influences on complex ecosystem-level processes. Various pollutant effects that are dangerous not only to the forests themselves, as an important resource, but also as an invaluable part of the human environment can be predicted by ecosystem-level research. In this sense one can consider the forest ecosystems as sensitive warning systems for the vital, fundamental interests of life.

atural Influences of Forests on Local nd Regional Air Quality

Emissions and Air Resource Management Within Forests[1]

Michael A. Fosberg and Hollis Record[2]

Abstract: Substantial portions of the emissions inventory within forested lands are from dispersed intermittent sources. Chief sources are smoke from wildfire and prescribed fire, emissions associated with concentrated recreation and second-home developments, and fugitive dust from unpaved roads and eolian soils. Effects of smoke on flora range from reduced photosynthetic efficiency at low dosages to tissue necrosis at high dosages. Effects on fauna are not clearly defined. Effect of smoke on social values, primarily visibility, is recognized but not understood. Dispersion process in complex terrain, the physiographic setting for most forested lands, is complicated by topography and spatially varying wind fields, a higher degree of anisotropy of turbulence, and a wider range of turbulence intensities than found over level ground. Management of air resources within forested areas is limited to land management planning activities because of the complexity of emission characteristics, dispersion processes, and effects of pollutants from within forest sources.

Much of this symposium treats effects of pol- lants from major stationary sources on eco- tems. Significant pollutants treated in other ers are nitrous oxides, oxides of sulfur, reac- e hydrocarbons, and the photochemical derived lutant, ozone. Effects of NO_2, SO_2, and O_3 are l documented in the companion papers in this ume.

Pollutants from within forest sources also lude emission from wildfire, prescribed fire, aved roads, eolian soils, concentrated recrea- n, and second-home developments, Chief emissions from fire are CO_2, CO, particulates, and hydrocarbons. Recreational and second-home developments emit CO_2, CO, particulates, and hydrocarbons from fireplaces and campfires; SO_2 and NO_x from dispersed transportation systems--namely, private automobiles. Fugitive dust from unpaved roads and eolian soils also contribute to the particulate loading.

Effects of the above pollutants, particularly smoke, flora, fauna, and social values are poorly understood. Documented effects range from reduced photosynthetic activity through blockage of solar radiation to tissue necrosis. Effects on microorganisms range from inhibition of some spores and fungi to increased germination of one fungus. Effects of smoke on fauna are documented, but without explanation.

Visibility is both a physical and social value. Visibility can be quantified in terms of visual range and ability to define details at specified distances. Visibility is also a personal value based on past and expected experiences. A recent popular country and western song (McCall and others 1976) goes "..... One of the guys from New York said 'Hey, look at the smog in the sky, smog clear out here in the sticks'. Someone said, 'Hey Joe,

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that's not smog, that's the Milky Way', Joe had never seen the Milky Way ...." Contrast Joe's reaction to that of a resident of the Four Corners area of Utah visiting any urban area in the world on a clear air day. Local residents would comment on the clarity of the air, but the visitor would notice the impairment of visibility.

The relationship between a source of pollution and the effect of that pollutant on Mediterranean and temperate forest ecosystems is through dispersion of the pollutant between the source and the receptor point. Nearly all dispersion calculations are based on the Gaussian model in which transport is treated through definition of a mean windspeed and direction and turbulent diffusion is based on a transformation of the turbulence structure to a Gaussian statistical distribution (Turner 1969). Validity of the coefficients used in the Gaussian model are uncertain in situations where terrain features are complex. In particular, winds are known to contain a high degree of spatial and temporal variability (Fosberg and others 1980) and the turbulence intensities are highly anisotropic.[3] Because much of the Mediterranean and temperate forest ecosystems are found in complex terrain throughout the world, the dispersion or delivery system of pollutants from the source to the receptor must account for complex terrain atmospheric processes.

An understanding of each physical and biological process is necessary but not sufficient to develop management plans for air resources within forests and brushlands. Acts, laws, regulations, and codes established by Congress down through local county regulatory agencies specify goals and objectives for air quality and frequently specify the methods in which air quality objectives will be met. As example, organic acts of most Federal agencies in the United States require that the agency protect or preserve, or meet air quality objectives. The Clean Air Act of 1977 (U.S. Congress 1977) specifically requires that air quality objectives be met through emissions control. Because it is not feasible to install scrubbers on prescribed fire, emission control is achieved through emissions density planning.

Each of the following sections addresses the specific topics of emission characterization, dispersion in complex terrain, effects of smoke on flora, fauna, social values, and air resource management.

EMISSIONS FROM WITHIN FOREST SOURCES

Major emissions from wildfire and prescribed fire are CO_2, CO, hydrocarbons, and particulates.

[3] Lanham, Lucy M. 1980. Wintertime dispersion processes in the Lake Tahoe Basins. Proc. 2nd Conf. on Application of Air Pollution Meteorology. Amer. Meteorol. Soc. [in press]

Although CO_2 is not a pollutant as such, CO_2 is o considerable interest in analysis of the globa heat balance. Carbon dioxide emissions range fro 1000 kg per metric ton of fuel to 1750 kg pe metric ton of fuel (Ryan and McMahon 1976), wit extreme values near 1830 kg per metric ton (Vine and others 1971).

Carbon monoxide emissions from fire are highl dependent on combustion efficiency. Values rang from 17 to 98 kg per metric ton (Sandberg an Martin 1975, Darley and others 1966, Gerstle an Kemnitz 1967). The U.S. Environmental Protectio Agency (1978) recommends a value of 45 kg pe metric ton from hemlock, Douglas-fir, and cedar an 98 kg per metric ton from ponderosa pine. Inefficient combustion for smoldering damp fuels hav resulted in emissions as high as 250 kg per metri ton of fuel (Ryan and McMahon 1976). Emissions a high as 250 to 400 kg per metric ton of fuel hav been reported when energy release from fire is les than 750 watts per square meter (Sandberg ar Martin 1975).

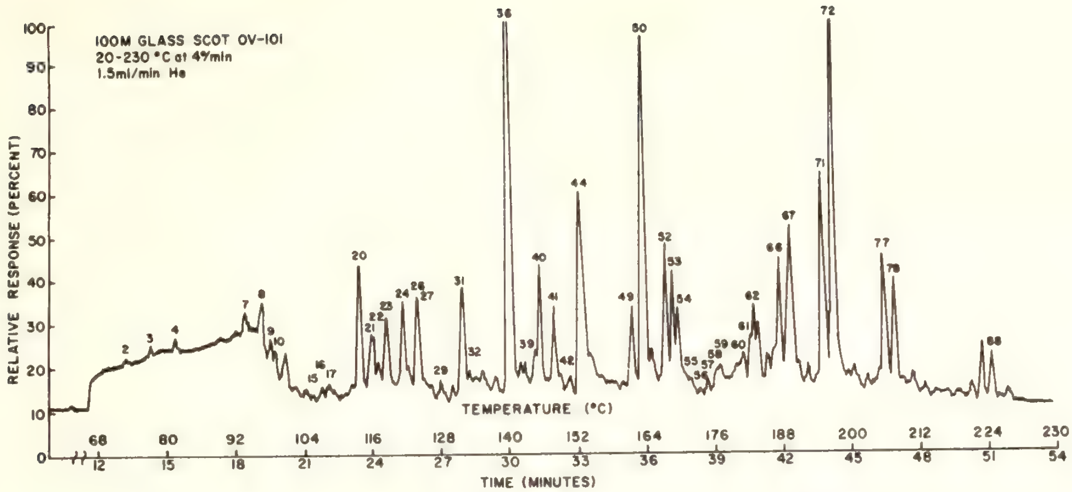
Hydrocarbon emissions range from 2 to 7 kg pe metric ton of fuel (U.S. Environmental Protectic Agency 1978) although emissions as high as 20 k per metric ton have been reported (Ryan and McMahc 1976, Darley and others 1966). Speciation c hydrocarbons (fig. 1) shows saturated hydrocarbo (mostly methane) comprise about 30 percent at pea fire intensity and about 15 percent at low fir intensities (Sandberg and others 1979). Lo molecular weight olofines make up about 17 percer of the emission from flaming fire and 3 percer from smoldering fire (Sandberg and others 1979)

Emissions of SO_x and NO_x are negligible. Mos fuel contains less than 0.2 percent sulfur and com bustion temperatures are low, preventing formati of NO_x.

Particulate emissions from fire are given as to 6 kg per metric ton of fuel (U.S. Environment Protection Agency 1978). A range of emissions a given in table 1. Particulate sizes are mainly the submicron diameter classes with only a f particles larger than a micron (fig. 2). Particu late sizes are dependent on combustion efficien (Schaefer 1976) with the most efficient fir producing sizes in the respirable range.

National emissions of particulates from pr scribed fires and wildfires are shown in figure Prescribed fire consists of less than 20 percent all fire emissions nationally. Emissions of t major pollutants, particulates, CO, and hydr carbons by State and regions are given in table for prescribed burning.

In addition to wildfire and prescribed fir concentrated recreation and second-home develo ments contribute smoke through fireplace burni and more increasingly through use of wood for ho heating.



PEAK	COMPOUND
2	isopentane
2B	1-pentene
2C	furan
3	n-pentane
3A	isoprene
3B	acetone
4A	isopropanol
4B	cyclopentadiene
7	diacetyl
8	1-hexene
8A	methyl vinyl ketone
9	2-methylfuran
10	n-hexane
15	2,4-hexadiene
16	1,3,5-hexatriene
17	3-methylbutanal
20	benzene
21	cyclohexane
22	4-methylpentene
23	2,4-dimethylpentane
24	1-trans-2-dimethyl-cyclopentane
24A	sorbaldehyde (tent.)
26	2,5-dimethylfuran
26A	n-heptane
27	cis-2-heptane
29	2-vinylfuran
31	2,3-dimethyl-2-pentane
32	2,4-dimethylhexane
36	toluene
39	1-octene
40	2,3-dimethylhexa-1,4-diene
41	n-octane
42	2,3,5-trimethylfuran
44	furfural
49	ethyl benzene
50	p-xylene
50A	2-propionylfuran (tent.)
52	styrene
53	o-xylene
54	n-nonane
54A	2-isopropylfuran
55	anisole
56	2-methyl-5-isopropenylfuran
57	cumene
58	n-decane
59	camphene (tent.)
60	n-propylbenzene
61	m-ethyltoluene
62	p-ethyltoluene
66	1-decene
67	benzofuran
71	m-diethylbenzene
72	limonene
77	p-α-dimethylstyrene
78	n-undecane
88	n-dodecane

Figure 1--Chromatogram of organic vapors in loblolly pine smoke (from Ryan and McMahon 1976).

Table 1--Summary of particulate emission yields reported from wildland fuels (from Sandberg and others 1979)

Fuel type	Lab/field experiment	Particulates (kg per metric ton of fuel burned) — Type of fire: Heading	Backing	Reference
L:gging residues (Western)	Field	14-53		Sandberg (1974)
	Laboratory		3-12	Sandberg (1974)
	Field	≈40		Radke and others (1978)
	Laboratory		2	Fritschen and others (1970)
L:dscape refuse	Laboratory		12	Feldstein and others (1963)
G:ss burning	Field		8	Boubel and others (1969)
L'e understory (Australia)	Field	7-20		Vines and others (1971)
	Laboratory	14-20		Vines and others (1971)
(Southern)	Field		7-15	Ward and others (1976)
	Laboratory		12-49	Ryan (1974)
P'e litter (Southern)	Field		22-27	Ward and others (1976)
	Laboratory		3-14	Ryan and McMahon (1976)
	Laboratory	11-63		Ryan and McMahon (1976)

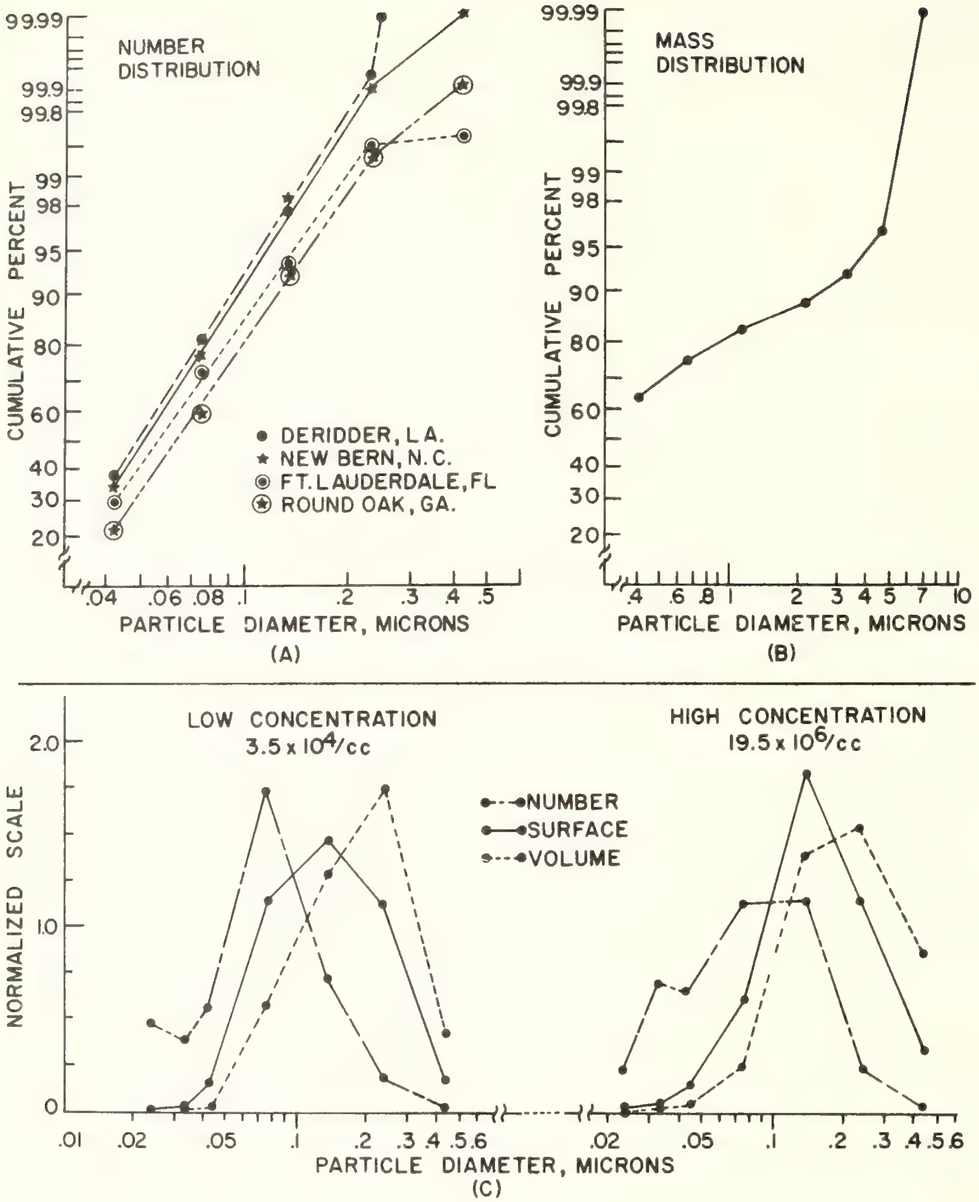


Figure 2--Particle size distribution: (A) Single fire in four fuel types; (B) Grand Average, all fuel types; and (C) Normalized distribution, number, surface area, and volume for a high and low concentration (from Ryan and McMahon 1976).

Some hydrocarbons and NO_x are also emitted from transportation systems and private vehicles in recreational and second-home developments.

Fugitive dust from unpaved roads and eolian soils occasionally contribute substantially to the particulate location of pollutants, but this has not been completely quantified (Singer 1980).

EFFECTS OF SMOKE ON FORESTS

Few studies exist that clearly define the effects of smoke and forest biota. Effects of smoke on micro-organisms suggest that smoke reduced growth of spore germination of several fungal pathogens, but increased spore germination on one fungi (Parmeter and Uhrenholt 1975a, b). Effec of smoke on photosynthesis at low dosages reduc the photosynthetic rate by direct blockage of sol radiation. Increased CO_2 concentrations, howeve, could increase carbon fixation and photosynthet activity (Green and Wright 1977).

Effects of smoke on social values, primari visibility, are not clearly defined. Althou physical aspects of visibility; that is, visu range, maximum distance an object can be seen, a discrimination of details on a distant object c be defined quantitatively (Malm 1979), percei psychological benefits (Driver and others 1979) f visibility are interrelated with other demands n the sensory system. Paraphrasing Driver and othe (1979) a little noise pollution, a little lig

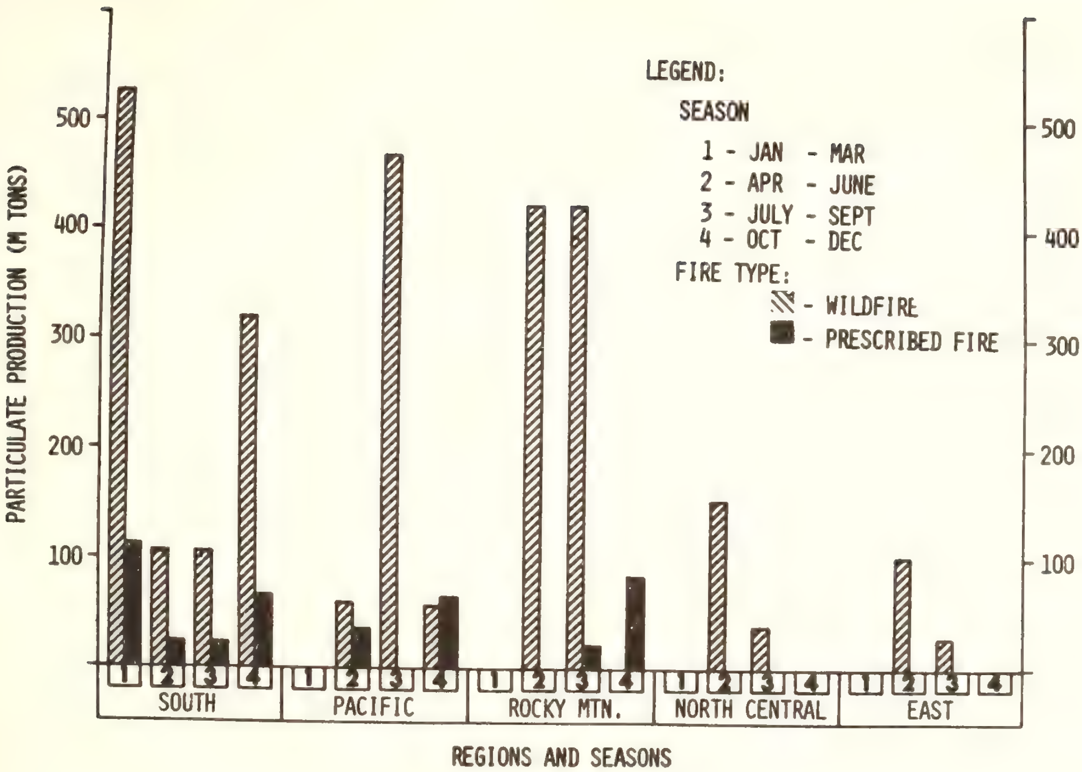


Figure 3--Forest fire particulate production by region and season (from Ward and others 1976).

lution, a little loss of open space, awareness d water pollution, nonbiodegradable substances, osol cans and cancer, change expected values of ibility. Referring to the quote from a popular g used in the introduction of this paper, we can , did Joe's attitudes toward visibility change his visit to Colorado, and how would those nges influence his view of the New York skyline? point Driver and others (1979) are emphasizing that the perceived values are the real values that the physically measurable values of visi- ity are indices of the values. In particular, ttering and attenuation of light is not a social ue.

DISPERSION PROCESSES IN COMPLEX TERRAIN

Wind patterns in complex terrain are highly iable in time and space. Local mountain and ley circulations frequently mask the large-scale erns such that a mean transport wind for pol- ant movement is difficult to define (Fosberg and ers 1976a, b; Fosberg and Fox 1978). Spatial iability of winds is clearly illustrated in ure 4 over the Oregon Coast Range and over the ade Mountains. Contrast this variability with uniformity of winds over the Pacific Ocean and in the Willamette Valley.

n addition to mean transport of pollutants, ulent diffusion is important in dispersing air pollutants. The most frequently used method of quantifying the dispersion process is through the so-called Gaussian dispersion model (Turner 1969). Downwind concentrations, χ, are related to emission Q by

$$\chi = \frac{Q\ G}{u} \tag{1}$$

where u is the mean windspeed and

$$G = \frac{1}{2\pi\sigma_y\sigma_z} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2 - \frac{1}{2}\left(\frac{z}{\sigma_z}\right)^2\right] \tag{2}$$

Here, σ_y and σ_z are the variances in the Gaussian statistical distribution; y and z are the distance of the pollutant element from the plance centerline. The variance σ is related to the turbulence structure through

$$\sigma^2 = \frac{2Kx}{u} \tag{3}$$

in which K is the eddy turbulence coefficient and x is the distance downwind from the source. Traditional interpretations of atmospheric processes that were developed for level ground suggest that the K's be defined through analysis of the inertial subrange of turbulence and that this mean wind is constant over substantial distances, this is, 10's of km. Such assumptions are extremely difficult to satisfy in complex terrain.

Table 2--Summary of prescribed fire acres burned and tons of criteria pollutant emitted (by geographic region, annual basis) (from Sandberg and others 1979)

States by Region	Area hectares (10^3)	Fuel consumed Metric tons/ha	Fuel consumed Metric tons (10^3)	Particulates 8 kg/metric tons	Carbon monoxide 10 kg/metric tons	Hydrocarbon 5 kg/metric tons
California	5	157	768	6,529	7,682	3,841
Oregon	37	74	2,740	23,290	27,400	13,700
Washington	45	76	3,457	29,380	34,566	17,283
Total	87		6,966	59,209	69,658	34,829
ROCKY MTN.						
Arizona	11	18	189	1,604	1,887	943
Colorado	1	18	19	161	190	95
Idaho	11	146	1,645	13,985	16,453	8,226
Montana	19	101	1,918	16,305	19,183	9,592
New Mexico	3	18	52	439	517	258
North Dakota	1	4	4	31	36	18
Total	46		3,826	32,519	38,257	19,129
N. CENTRAL						
Michigan	1	7	8	69	82	41
Minnesota	2	7	16	139	163	82
Wisconsin	3	7	18	154	181	91
Total	6		44	365	435	218
EASTERN						
Delaware	0	4	2	15	18	9
New Jersey	8	7	54	463	544	272
Total	8		56	478	562	281
SOUTHERN						
Alabama	85	7	568	4,826	5,678	2,839
Arkansas	22	7	149	1,264	1,487	744
Florida	291	9	2,609	22,173	26,085	13,043
Georgia	293	7	1,972	16,760	19,718	9,859
Louisiana	89	7	600	5,104	6,004	3,002
Mississippi	68	7	460	3,908	4,598	2,299
N. Carolina	47	7	319	2,714	3,192	1,596
S. Carolina	157	7	1,058	8,989	10,576	5,288
Texas	34	7	227	1,927	2,268	1,134
Virginia	13	11	144	1,225	1,442	721
Total	1,100		8,100	68,887	80,995	40,498
USA Total	1,197		18,991	161,422	189,908	94,954

An alternative method of defining the variances for complex terrain is mathematically identical but does not require that the turbulence lie in a particular portion of the energy spectrum (Fosberg and others 1976b, Fosberg and Fox 1978). In particular, a mean wind is defined statistically over the dispersion distance of interest. Deviation of wind about this mean, whether in the turbulent inertial subrange or produced by organized flows of scale smaller than the averaging distances, are treated mathematically as components of K. The deviations about the statistically defined mean wind are u'. The K's are then defined by

$$K = \overline{u'^2}\,\tau \qquad (4)$$

in which the line over the square of the deviations is the averaging operator. The time constant τ is related to the averaging time and space. These K's do not represent turbulence. Instead, the K's define the wind variability at scales smaller th those used to define the mean wind.

MANAGEMENT OF AIR RESOURCES

Emission control is required to meet air qual objectives (U.S. Congress 1977). Because dir limits on emission from open burning can achieved only by limiting the mass of fuel bur at any given time, a model for air resource al cation was developed. The Air Resource Allocat Model (ARAM) is based on the Gaussian dispers model defined in equation 1. Because the intent to limit emissions, equation 1 is rearranged

$$Q = \frac{\chi\, u}{G}$$

The concentration χ is interpreted here as increment of air quality available for prescri

Table 3--Change in annual burn (in hectares by pollutant)

Basin	C.O.	T.S.P.	H.C.
Monterey Ranger District			
1. Little Sur	5,260	9	757
2. Big Sur	5,260	9	757
3. Carmel	6,290	10	909
4. Arroyo Seco	12,700	21	1,840
5. Ocean Front	13,500	23	1,960
6. San Antonio	11,250	19	1,640
7. Nacimiento	8,590	13	1,210
Santa Lucia Ranger District			
8. Salinas (A)	5,110	85	3,170
9. Salinas (B)	1,080	10	365
10. Lopez Canyon	1,080	10	363
11. Cuyama (A)	43,000	297	5,660
12. Sisquoc	193,000	298	25,400
Mount Pinos Ranger District			
13. Cuyama (B)	37,900	297	4,980
14. San Joaquin Valley	22,800	189	3,010
15. Piru	24,300	201	3,190
Ojai Ranger District			
16. Sespe	20,500	170	2,700
17. Santa Paula	6,200	-17	no data
18. Ventura	25,500	-70	no data
Santa Barbara Ranger District			
19. Santa Ynez	27,500	190	3,620
20. Santa Barbara Front	17,300	-29	-7,760

ning. ARAM is based on earlier development on ssion limits for single sources, single receptor ations defined in the TAPAS model (Fosberg and 1976, Fox and Fosberg 1976). ARAM differs from AS in that ARAM considers multiple sources and tiple receptor sites and contains improvements n characterization of the dispersion processes. ations between multiple sources and multiple eptor sites are defined through matrix algebra s

$$\chi_1 = \frac{Q_1G_{11}}{u} + \frac{Q_2G_{21}}{u} + \ldots \qquad (6a)$$

$$\chi_2 = \frac{Q_1G_{12}}{u} + \frac{Q_2G_{22}}{u} + \ldots \qquad (6b)$$

ere χ_1, χ_2, and so on are the increments of ution allowed at receptor sites 1, 2, and so Q_1, Q_2,... are the allowable emissions at ce sites 1, 2,... and G_{11} is the dispersion tion between source 1 and receptor 1; G_{21} is dispersion relative between source 2 and ptor 1, and so on. Expressing equation 6 in ix format

$$|\chi_i| = \frac{|Q_j||G_{ji}|}{u} \qquad (7)$$

The generalized form of ARAM expressed in equation 5 is this

$$|Q_j| = |\chi_i||G_{ji}|^{-1}u$$

ARAM has been applied on one National Forest in California, the Los Padres, in support of use of prescribed fire in vegetation management. Current air quality regulations in California recognize that prescribed fire is an alternative to wildfire for vegetation management. In particular, the regulatory agencies accept the concept that a ton of fuel burned in prescribed fire can be used to offset a ton of fuel burned in wildfire.

In the following example, the increment for prescribed burning is defined as the incremental departure from the existing emission from prescribed fire and wildfires. This approach circumvents the difficulties associated with development of a complete regionwide emission inventory base. The assumption here is that the existing emission from prescribed fire and wildfire are defined within the State Implementation Plan. The following calculations then represent an analysis of

where prescribed burning can be increased and where burning must be reduced. The air quality database is the California Air Resources Board (1977) Three-Year Summary of Air Quality. Nearly all the air quality monitoring stations are in urban areas and, therefore, do not necessarily reflect conditions in the wildlands. The following calculations are conservative estimates because of the bias in the database. The meteorological database is from the National Fire Weather Library (Furman and Brink 1975). This database is the only readily accessible database for wildlands. Plume rise calculations were made through the equations developed by Craig and Wolf (1980) for prescribed burning. Three criteria pollutants were evaluated. These pollutants were particulates, hydrocarbons, and carbon monoxide.

The physical setting of the Los Padres National Forest is along the California Coast extending from near Monterey in the north, around Point Conception, to near Santa Barbara in the California Bight. The Los Padres National Forest lies withi the California Coast Range and, therefore, can l broken up into a series of small airsheds.] particular, 20 airsheds were defined. Severa Class I wilderness areas are included. Emissio in each of the airsheds were converted to hectar through a fuels inventory of tons of fuel p hectare and the emission characteristics defined the second section of this paper. Calculat changes in combined emissions of prescribed a wildfires are defined by this least acres f increase or largest negative numbers for decrea from current emissions. As an example, all ai sheds on the Monterey District are limited particulate pollutants (table 3). Most airsheds the Los Padres National Forest could sustain min increases in prescribed burning. Only three ai sheds show a need to decrease the combined pr scribed fire, wildfire emissions. All three ai sheds are heavily populated, and the Forest mu compete with numerous other pollutant sources f the air resource.

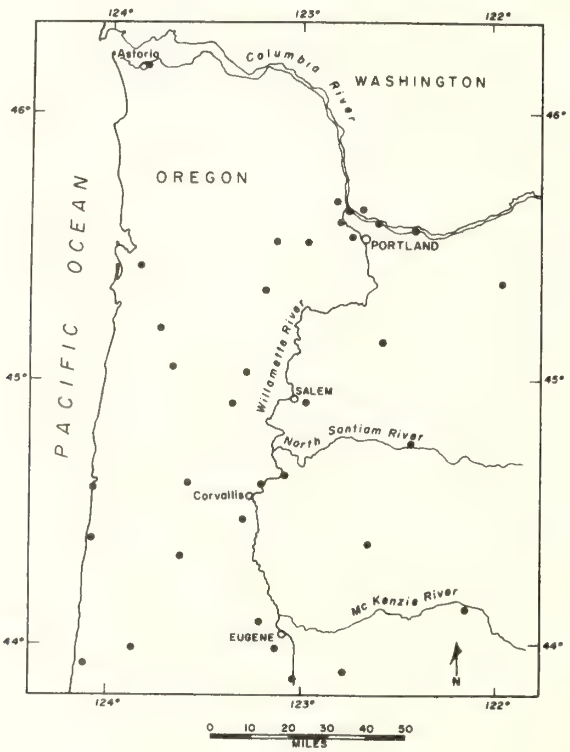


Figure 4a--Location of weather stations in northwest Oregon used to calculate wind patterns shown in figure 4b.

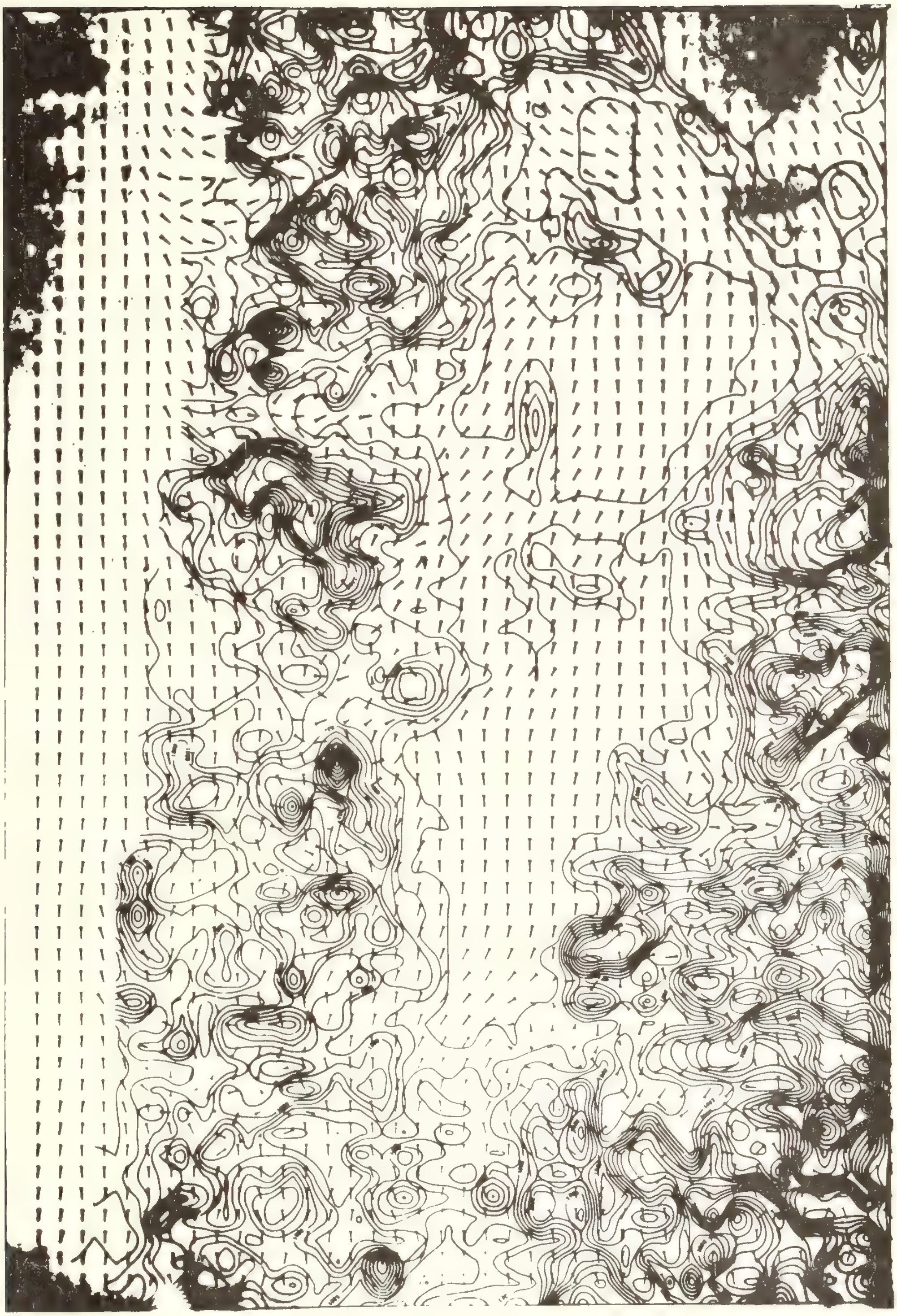


Figure 4b--Calculated wind patterns. Mesh length is 4 km by 4 km. Windspeed is proportional to length of arrows. Note the uniformity of wind direction and speed over the Pacific Ocean and within the Willamette Valley. Winds in complex terrain, the Coast Range, and the Cascade Range show a high degree of speed and direction variability.

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Hydrocarbon Emissions from Vegetation[1]

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Abstract: A wide range of volatile organic compounds may be emitted by vegetation. The identified emittants, however, are mainly terpenoid in nature. Their emission rates are controlled primarily by the physical/chemical processes that regulate hydrocarbon vapor pressure. Emission rates vary between species and are influenced by environmental factors such as light and temperature. Regional emission estimates indicate that vegetation may emit as much as 30 kg of hydrocarbons km^{-2} day^{-1}. The measured atmospheric concentrations are in reasonable agreement with the estimated emission rates. Within the atmosphere, these hydrocarbons may participate in photochemical reactions leading to aerosol production and the consumption or formation of ozone.

High levels of ozone have been measured in rural and remote locations far from significant anthropogenic sources of oxidant precursors. These elevated concentrations may have resulted from long distance transport and/or the photooxidation of locally-produced biogenic hydrocarbons. Robinson (1978) proposed that ambient hydrocarbon concentrations were governed by both long distance transport and local production. Volatile organics, including monoterpenes and isoprene, have been detected in the atmosphere (Rasmussen and Went 1965; Schjoldager and Watine 1978; Whitby and Coffey 1977; Arnts and Meeks 1980; Lonneman and others 1977) and in laboratory studies shown to produce ozone (Arnts and Gay 1979), suggesting that they may contribute to ambient ozone concentrations.

Plants contain a number of potentially volatile organic compounds including monoterpenes, isoprene, aldehydes, alcohols, and ketones (Meigh 1955; Rasmussen 1972; Zimmerman 1979a). Indivi ual species have relatively distinctive emissi profiles. For some species, only one or a f compounds dominate the emission profile; howeve other species have a diffuse emission profile wi no dominant compounds (Rasmussen 1972; Zimmerm 1979a). Despite the wide range of potential volatile compounds, only isoprene, monoterpene and a few aromatics have been conclusively ident fied as emission products from vegetati (Rasmussen 1972; Zimmerman 1979a), hence they fo the basis for further discussion.

METHODS FOR ESTIMATING EMISSION RATES

A variety of experimental methods have be used to estimate emission rates. A tree branch a few small plants were enclosed in a large Tefl bag to estimate biogenic hydrocarbon emissi rates in the field (Zimmerman 1979a, 1979b). T bag was sealed, evacuated and refilled with hydr carbon-free air. A small gas-exchange rate w maintained through the bag. After an accumulati period, the head space was sampled to determi the gas phase concentration. Vertical gradie of temperature, water, and α-pinene, both with and above the canopy of a loblolly pine (Pi taeda L.) plantation were measured and used calculate emission rates (Arnts and others 197

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Semi-quantitative estimates of emission rates were made using static gas-exchange chambers containing either detached leaves, twigs or whole plants (Rasmussen 1970; Rasmussen 1972; Sanadze and Kalandadze 1966a). Within these chambers carbon dioxide may be elevated or depleted depending on light intensity. This may modify plant metabolism and the stomatal aperture; humidity will increase; and high concentrations of hydrocarbon gases will build up within the chamber reducing diffusion gradients. These factors can lead to an underestimation of emission rates. Dynamic mass-balance gas-exchange chambers and leaf cuvettes which simulate the gaseous environments of plants in the field have also been used to estimate hydrocarbon emissions (Kamiyama and others 1978; Tingey and others 1979 and 1980; Tyson and others 1974). These chambers may be used to determine the influence of environmental factors on emission rates.

MECHANISM OF HYDROCARBON VOLATILIZATION

Terpenoid Biosynthesis

Knowledge of the mechanism and sites of terpenoid biosynthesis aids in understanding the factors controlling emission rates. Terpenoid biosynthesis starts with the conversion of carbon dioxide to sucrose with its subsequent metabolism to acetyl-CoA and mevalonic acid to form isopentenyl pyrophosphate. The hemiterpene, isoprene, (C_5) is formed from isopentenyl pyrophosphate; monoterpenes (C_{10}) are formed from a condensation of dimethylallyl pyrophosphate and isopentenyl pyrophosphate. Subsequent additions of isopentenyl pyrophosphate units form higher homologs in the terpenoid series (Loomis and Croteau 1980).

The conditions that promote isoprene biosynthesis indicate that it is likely synthesized within the chloroplast. Isoprene biosynthesis is affected by metabolic inhibitors that regulate photorespiration (Loomis and Croteau 1980).

Monoterpenes appear to be ubiquitous in higher plants (Loomis and Croteau 1980). The accumulation or secretion of significant quantities of monoterpenes is associated with the presence of secretory structures such as glandular hairs or trichomes, oil cells, resin ducts or glandular epidermises, and lysogenous spaces. It is generally assumed that monoterpenes are synthesized within the secretory cells, although this point has not yet been conclusively demonstrated (Loomis and Croteau 1980).

Hydrocarbon Diffusion from Plants

Gaseous diffusion between the plant and its environment is controlled by the chemical potential gradient between the inside and the outside of the leaf and the resistance to mass transfer along the diffusion pathway. The chemical potential gradient can be approximated by a concentration gradient. The larger the concentration gradient, the larger the hydrocarbon flux; conversely, the larger the resistance to mass transfer, the smaller the flux (Nobel 1974).

Only hydrocarbons with appreciable vapor pressures at ambient temperatures will be emitted at significant rates. The vapor phase concentration of hydrocarbons within the leaf is controlled by the liquid phase concentration, vapor pressure, and solubility. The vapor pressure of terpenoid compounds increases exponentially with the temperature (Jordan 1954). Monoterpene emission rates from black sage (Salvia mellifera Greene) and slash pine (Pinus elliottii Engelm.) also exhibit an exponential increase with temperature (Dement and others 1975; Tingey and others 1980), indicating that vapor pressure is a significant factor in controlling emissions. Emission rates from dead slash pine needles and black sage leaves are similar to emission rates from live tissue (Tingey and others 1980; Dement and others 1975), supporting the concept that the volatilization is primarily a physical process. Hydrocarbons with chain lengths greater than C_{10} generally have low vapor pressures and will not have a large emission rate.

When monoterpenes occur in high concentrations in resin ducts, oil cells or glandular trichomes, their emission rates are essentially independent of concentration. Large pools of isoprene, however, have not been detected. Below 35°C (the boiling point for isoprene), the emission rate is closely linked to its synthesis rate. Above 35°C, the emission rate is diffusion-limited (Tingey and others 1979).

Monoterpenes have a low aqueous solubility (hydrophobic) and higher vapor pressures than similar, more hydrophilic compounds. Therefore, monoterpenes would be emitted at a higher rate than similar oxygenated compounds at equal concentrations within the tissue. Similarly, if the concentration exceeds its aqueous solubility limit, then vapor pressure and emissions are independent of tissue concentrations.

Resistance to mass transfer can occur along either a stomatal or cuticular pathway (Nobel 1974). Either one or both pathways may be significant, depending on the species. Stomata are apparently the main pathway for diffusion of monoterpenes (Hanover 1972), isoprene and other compounds synthesized within the leaves. However, for plants with glandular trichomes or glandular cells in the epidermis, such as in the Labiatae and Solanaceae, the cuticular pathway is the main one for diffusion.

BIOGENIC EMISSIONS

Emission Rates

Emission rates for several plant species are shown in table 1. Total non-methane hydrocarbon and monoterpene emission rates are similar among

Table 1--Biogenic hydrocarbon emission rates estimated at 30°C.

Species	TNMHC[1]	Isoprene	Monoterpenes	References
	—μg [g dry weight]$^{-1}$ hr^{-1}—			
Slash Pine	4.1		2.6	Zimmerman 1979a
Longleaf Pine	7.3		5.6	Zimmerman 1979a
Sand Pine	13.6		11.0	Zimmerman 1979a
Cypress	14.2		8.1	Zimmerman 1979a
Slash Pine			6.4	Tingey and others 1980
Loblolly Pine			3.7	Arnts and others 1978
Cryptomeria			3.0	Kamiyama and others 1978
Laurel Oak	12.6	10.0		Zimmerman 1979a
Turkey Oak	26.5	23.4		Zimmerman 1979a
Bluejack Oak	56.4	43.9		Zimmerman 1979a
Live Oak	10.8	9.1		Zimmerman 1979a
Live Oak		41.2		Tingey and others 1980
Willow	22.1	12.4		Zimmerman 1979a
Saw Palmetto	11.5	8.6		Zimmerman 1979a
Mean 7 Hardwood Trees--Isoprene	20.0	15.7		Flyckt and others 1980
Wax Myrtle	7.5			Zimmerman 1979a
Persimmon	2.9			Zimmerman 1979a
Orange	9.4			Zimmerman 1979a
Grapefruit	4.3			Zimmerman 1979a
Red Maple	6.5			Zimmerman, 1979a
Hickory	3.2			Zimmerman, 1979a
Mean 10 Hardwood Trees--Non-Isoprene	7.3			Flyckt and others, 1980

[1] Total non-methane hydrocarbons.

the conifers and as much as 50 percent less than emission rates from hardwoods that emit isoprene. Monoterpenes account for 50 to 75 percent of the total non-methane hydrocarbon emissions in conifers. Similarly, isoprene accounts for 60 to 90 percent of total non-methane hydrocarbon emissions from isoprene emitters. Plants whose emissions were not dominated by either isoprene or a few monoterpenes had emission rates roughly similar to the conifers.

Total non-methane emission rates were estimated at several locations in the United States on similar vegetation types:

Vegetation Type and Location:	Emission Rate[1] (μg [g dry weight]$^{-1}$ hr^{-1})
Conifers	
Washington	5.0
Florida	8.8
Texas	5.0
Oaks	
California	28.7
Florida	21.9
Texas	26.0
Non-Conifers, Non-Isoprene Emitter	
Washington	7.8
California	4.1
Florida	4.7
Texas	0.2

[1] Data from Zimmerman 1979b and c.

Emission rates for the conifers, oaks and non-conifer, non-isoprene emitting vegetation are similar within each vegetation type. This indicates an apparent high uniformity in emission rates among locations using the same estimation technique.

Hydrocarbon emission rates/unit tissue multiplied by biomass density yield emission factors. Emission factors for the Tampa-St.Petersburg, Florida, area (Zimmerman 1979a), indicate that 2 percent of the total non-methane hydrocarbon emissions occur in the following four land use types: evergreen forests (35 percent); citrus groves (2 percent); pasture and rangeland (19 percent); and residential areas (16 percent). The remaining 8 percent was distributed among crop lands, deciduous forests, mangroves, freshwater, marine, and barren lands. Emission factors for trees were approximately 6 mg m^{-2} hr^{-1}; shrubs, 2.0 mg m^{-2} hr^{-1}; pastures, mud flats and other land use types were less than 0.1 mg m^{-2} hr^{-1}.

Emission factors were developed to characterize the various biomes in the United States:

Biome:	Emission Rate (mg m^{-2} hr^{-1})[1] Day	Night
Grassland	0.3	0.2
Sclerophyll Scrub	2.4	1.4
Temperate Rain Forest	10.7	9.4
Deciduous Forest	6.6	2.7
Coniferous Forest	6.5	2.7
Desert	1.3	0.7
Tundra, Alpine Fields	0.5	0.4

[1] Data from Zimmerman 1979b.

Daytime biome emission factors ranged from a low of 0.3 mg m^{-2} hr^{-1} for grasslands to a high of 10.7 for temperate rain forests. Nighttime emissions were 10 to 60 percent lower reflecting, in part, the absence of isoprene emissions.

Environmental Influences on Emission Rates

Isoprene production is light dependent, and persists for only a few minutes when plants are darkened (Rasmussen and Jones 1973; Sanadze and Kalanadze 1966b). Emissions increase with increasing light intensity until a maximum is reached and then remain constant (Sanadze and Kalandadze 1966a; Tingey and others 1979); similar to a light saturation curve for photosynthesis. Isoprene emissions are light saturated at moderate light intensities (Sanadze and Kalandadze 196 ; Tingey and others 1979). In contrast, monoterpene emissions from slash pine, black sage, and several other plant species, are similar in the dark and light (Tingey and others 1980; Dement and others 1975; Rasmussen 1972).

Isoprene emissions increase sigmoidally with temperature; low emissions occur at 18-20°C and increase exponentially between approximately 30 and 35°C, then plateau. At higher temperatures (between 43 and 47°C), depending upon the species, there is the large, precipitous decline in isoprene emissions (Sanadze and Kalandadze 196 ; Rasmussen and Jones 1973; Tingey and others 198 .

e increase in isoprene emissions with temper-ure is greater at high light intensities than w (Tingey and others 1979). Isoprene emissions om several hardwood trees and live oak (Quercus rginiana Mill.) increased at approximately 20 d 16 percent/°C (20-35°C), respectively (Flyckt d others 1980; Tingey and others 1979).

Monoterpene emissions from conifers, black sage d hardwood trees increase exponentially with the mperature (Arnts and others 1978; Kamiyama and hers 1978; Rasmussen 1972; Flyckt and others 80; Dement and others 1975; Tingey and others 80). The relative percent increase per degree mperature varies between species and ranges from proximately 6 to 20 percent/°C. In conifers, tensive genetic variations in monoterpene pools anover 1972) may explain the lack of an exponen-al relationship between temperature and emission es in some field studies (Flyckt and others 30).

Typical diurnal emission patterns for isoprene d monoterpenes and environmental conditions for average of summer days in Tampa, Florida, were d to illustrate the interaction of light and perature on terpenoid emissions (Tingey and ers 1979, 1980). During early morning and late ernoon, when the leaves are not light-saturated l the temperature is moderate, light would be main factor controlling isoprene emissions m live oak. However, during most of the day, leaves of the canopy are light-saturated; thus ying air temperature would control emission es. More than 80 percent of the isoprene ssions were expected to occur after mid-ning, ceasing in the evening. Monoterpene ssion rates from slash pine increase after rise, peaking during early afternoon, and lining to a minimum shortly before sunrise. roximately 55 percent of the total daily mono-pene emissions occurred during daylight hours 00-1800) with an additional 25 percent emitted ween sunset (1800) and midnight (2400).

Seasonal emission patterns were estimated for ividual ponderosa pine and red oak trees yckt 1979). Monoterpene emissions from pon-osa pine were sinusoidal, at a maximum during e spring (May and June), declining to a minimum und November, and then gradually increasing. contrast, isoprene emissions from red oak were imum during July and August and decreased ing the fall. No isoprene emissions were ected during the winter; emissions reappeared the spring with the initiation of new leaves. is not clear whether seasonal emission changes e due solely to changes in environmental condi-ns or were, in part, due to changes in terpen-pools. In addition to changes in the emission es, there were also qualitative changes in the oterpene emissions throughout the year (Flyckt others 1980).

Table 2--Estimated emissions for biogenic hydrocarbons.

Location	Emissions	Emission Factors	References
	metric tons	kg km^{-2} day^{-1}	
World	1.75×10^8/year		Went 1960
World	4.38×10^8/year		Rasmussen and Went 1965
World	8.30×10^8/year		Zimmerman 1979b
United States	$0.23\text{-}4.64 \times 10^7$/year		Rasmussen 1972
United States	6.5×10^7/year		Zimmerman 1979b
Florida (81 x 60 km)	157.0/day	32.3	Zimmerman 1979a
Texas (38 x 31 km)	32.4/day	27.5	Zimmerman 1979c
Pennsylvania	3,580.0/day	30.7	Flyckt and others 1980

Regional Emissions

Biogenic hydrocarbon emission rates for a variety of plant species and biomass estimates, were used to estimate emissions for various areas (table 2). The emission rate estimates for various estimation scales (world, United States, or regional) were approximately similar. The close agreement between the emission estimates from the three regional studies may have occurred because the same experimental approach was used. Emission estimates for Pennsylvania and the Tampa-St.Petersburg, Florida, area indicate that biogenic emissions range from 12 percent greater to 20 percent less than anthropogenic emissions (Flyckt and others 1980; Zimmerman 1979a; Wayne and Kochis 1978).

Relationship Between Primary Productivity and Emission Rates

A relationship between biogenic hydrocarbon emissions and primary productivity should exist because they are ultimately derived from photosynthetically fixed carbon dioxide. Measurements of the ratio of carbon lost as volatile terpenoids to primary productivity for several tree species indicated loss rates of 0.2 to 2 percent for isoprene and 0.06 to 0.4 percent for monoterpenes (Sanadze 1969; Tingey and others 1979, 1980; Tyson and others 1974). The relationship between primary productivity and biogenic hydrocarbon emissions could be used to delineate geographic areas where emissions would tend to be high. Based on the work of Leith (1975), primary productivity is highest in the Southeast, followed by the Mississippi Valley area and the central part of the United States and lowest in the Great Basin and the Southwest. Zimmerman (1979b) estimated that 45 percent of the total national biogenic hydrocarbon emissions occurred in the South, an area with the highest primary productivity in the United States (Leith 1975).

AMBIENT CONCENTRATIONS OF TERPENOIDS

Biogenic hydrocarbons were measured in the atmosphere over several vegetation types. The average isoprene concentrations varied from 10 ppb carbon for an oak forest to 0.1 ppb carbon for a pine forest. The average monoterpene concentrations ranged from 24 ppb carbon in the coniferous

forest in Norway to 2.7 ppb carbon in the coniferous forest in Idaho (Schjoldager and Watine 1978; Arnts and Meeks 1980; Coffey and Westberg 1978). Measured ambient concentrations of biogenic hydrocarbons and ambient concentrations predicted from biogenic emission rates are in reasonable agreement (Zimmerman 1979c; Flyckt and others 1980; Scully, 1979; Coffey and Westberg, 1978).

Atmospheric hydrocarbon concentrations are dependent on emission rates, mixing height, and the reactivities (photolysis and ozonolysis) of the individual components. Peterson and Tingey (1980) used a box model to estimate ambient air concentrations of isoprene and monoterpenes. The predicted isoprene concentrations increased during the daylight hours, reaching a maximum at mid-afternoon and then disappearing during the early evening when isoprene emissions ceased. Predicted ambient monoterpene concentrations were the lowest during mid-day when atmospheric dilution, photooxidation, and ozonolysis, were the highest, despite the fact that monoterpene emissions were a maximum. In contrast, monoterpene concentrations were the largest during the evening and early morning hours because monoterpenes are emitted at night when atmospheric mixing is low and hydrocarbon decay reactions are slow, permitting an accumulation of monoterpenes. This predicted monoterpene profile was verified by field measurements (Arnts and Gay 1979).

ATMOSPHERIC FATES OF TERPENOIDS

There are several atmospheric fates for the biogenic hydrocarbons, including conversion to aerosols, carbon monoxide formation, and photochemical reactions, both forming and consuming oxidants. Went (1960) attributed the blue haze found over many coniferous forests to the conversion of terpenes to aerosols. When limonene, a monoterpene, was reacted with NO_x and O_3, greater than 50 percent of the limonene was converted to aerosols within 2.5 hours (Schuetzle and Rasmussen 1978). The aerosols contained both mono- and dimeric alcohols, aldehydes and acid-substituted products.

Zimmerman and others (1978) suggested that atmospheric isoprene and monotepenes could be oxidized in the atmosphere to CO with a yield of 60-80 percent. Based on biogenic emission estimates, they concluded that natural hydrocarbons may be the largest contributor to the United States carbon monoxide budget.

Nitrogen oxides in the presence of solar radiation form OH radicals (Cleveland and Graedel 1979). Hydroxyl (OH) radicals react with hydrocarbons, forming peroxy radicals, which in turn convert NO to NO_2, perturbing the photostationary state releasing a free oxygen, forming ozone and other oxygenated products. The exact mechanisms are not clearly delineated because of competing secondary reactions with hydrocarbons, O_3, NO_x, and OH radical. Arnts and Gay (1979) reported ozone, PAN, formic acid, acetone, aldehydes, C and CO_2 formation when terpenes were irradiated the presence of nitrogen oxides. The amount ozone formed depended on the C/NO_x ratio. At low C/NO_x ratio, 1 ppb C from terpenoids produc 2-4 ppb ozone. However, when the ratio was larg 1 ppb C produced 0.3 to 0.1 ppb ozone, suggesti that terpenoids also consume ozone. Eschenroed (1974) and Coffey and Westberg (1978) conclu that emissions of biogenic hydrocarbons did r significantly alter ambient ozone concentratio through scavenging reactions.

Zimmerman (1979c) suggested that photooxidati of isoprene from forests could contribute 22 p ozone to the ambient concentration. Similarl Coffey and Westberg (1978) suggested that emi sions from coniferous forests could react to add to 5 ppb ozone to the ambient air.

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Background Levels of Trace Elements in Forest Ecosystems[1]

G. Bruce Wiersma and Kenneth W. Brown[2]

Abstract: This study was conducted as part of a project to develop a pollutant monitoring system for biosphere reserves. Sampling was carried out in the Great Smoky Mountains National Park and Olympic National Park. Results are reported for copper, lead, manganese, aluminum, calcium and phosphorus. Olympic National Park had much lower levels of lead and copper than Great Smoky Mountains National Park. Moss appeared to be a good collector for lead and copper. Results indicate that reference levels for trace elements can be established for remote areas, although they cannot be considered true background levels.

Introduction

Biosphere reserves are remote, pristine areas set aside in perpetuity. A pollutant monitoring system is being developed for implementation on such reserves (Wiersma and others 1978a; Wiersma and others 1979). Purpose of monitoring pollutants on these areas are:

1. to serve as locales for background reference levels of certain pollutants

2. to provide a frame of reference against which changes in impacted areas can be measured

3. to reflect changes of a global nature before such changes are obvious in more impacted areas.

The reserves are areas that can be used to monitor the behavior of pollutants that have long range transport characteristics such as trace elements (Zoller and others 1974; Duce and others 1975; Thrane 1978; Weiss and others 1971; Scheslinger and others 1974; and Chow and Earl 1970).

Since many trace elements have the potential for long-term transport the question becomes, in a monitoring program for background areas, what elements should be of prime interest. Two parameters can be used to estimate potential for long-term transport. First, elements that have a high vapor pressure, and second, elements that would have a significant small particle (1.0 μ or less) association. There is evidence that these two phenomena may work in conjunction. Ondov and others (1977a) analyzed the relationships existing between particle size and elemental composition in power plant emissions. They stated that elements with low vapor pressures tended to be associated with larger particle sizes. In a subsequent paper Ondov and others (1977b) listed several elements as having significant small particle association including manganese, lead and copper.

Kyser and others (1978), using a variety of microprobe analytical techniques, found that arsenic, cadmium, cobalt, chromium, manganese, nickel, lead, sulphur antimony, selenium, thallium, vanadium and zinc were present on particles primarily as surface material. This lends further support to the hypothesis that

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[1]Presented at the Symposium on Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, June 22-27, 1980, Riverside, California, U.S.A.

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elements with high vapor pressure tend to condense on smaller particles.

Methods

Analytical

This paper will present data for trace element levels in vegetation and forest litter. The analytical procedure used was spark source emission spectroscopy (SSES) which determines 26 elements per sample. The analytical procedure has been previously described by Alexander and others (1975).

Every tenth sample submitted was a quality assurance sample, alternating between known value samples and replicated samples. Samples were submitted in a set order. The analytical laboratory was required to analyze the samples in the order submitted.

Field Sampling

Two biosphere reserves, the Great Smoky Mountains and Olympic National Park, have been sampled as part of a pilot research project to develop a cost effective pollutant monitoring system. Great Smoky Mountains National Park was originally sampled in the fall of 1977 and again in 1978. The results of this effort have been reported by Wiersma and others (1979). Olympic National Park was sampled in the summer of 1979.

Figures 1 and 2 show sample site locations for the Great Smoky and Olympic National Parks respectively. Details of the Olympic study design are presented by Brown and Wiersma (1979).

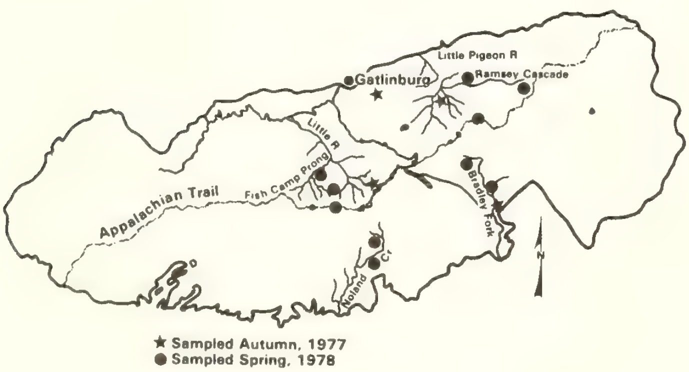


Figure 1--Sampling locations in the Great Smoky Mountains Biosphere Reserve.

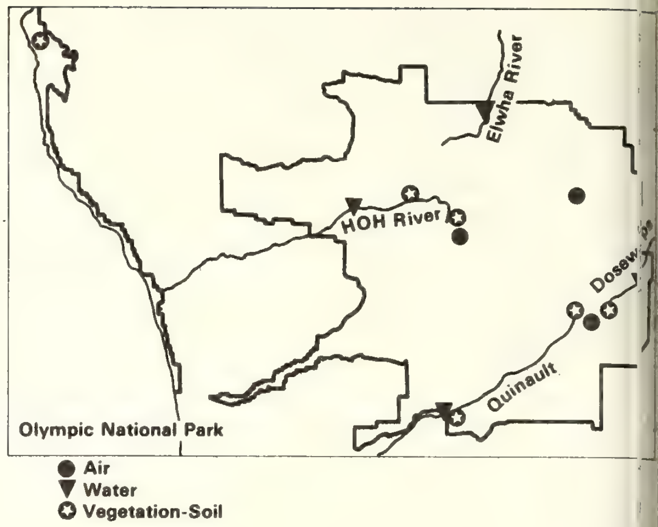


Figure 2--Sampling locations in the Olympic National Park Biosphere Reserve.

Results and Discussion

Trace Element Selection

The 26 trace elements analyzed by SSES are given in table 1.

Table 1--elements and detection limits for spar source emission spectroscopy.

Element	ppm	Element	ppm
P	50.0	V	1.0
Na	1.0	Co	1.5
K	150.0	Ni	0.5
Ca	1.0	Mo	0.2
Mg	50.0	Cr	0.2
Zn	5.0	Sr	0.2
Cu	0.2	Ba	0.2
Fe	0.6	Li	0.3
Mn	0.1	Ag	0.1
B	0.2	Sn	0.3
Al	0.1	Pb	1.0
Si	1.0	Be	0.2
Ti	0.5	Cd	3.0

Using this listing and selection criteria previously described, we are limiting our presentation in this paper to copper, lead and manganese. Also included are two biologically essential elements, calcium and phosphorus and one non-essential element, aluminum, which also is one of the elements which has the potential for long-term transport.

Quality assurance results are shown in table 2. od agreement exists between the analytical sults and certified levels. In addition, the plicated samples, which were analyzed sequenally, showed no drift and had acceptable producibility.

ble 2--Quality assurance results for elements om Great Smoky Mountains.

	Analytical results for QA samples µg/g	NBS reported values µg/g	Drift of replicated samples[1]
osphorus	1,950	2,000 to 2,200	Not significant
ad	44.7	44	Not significant
pper	12.0	11.0 to 13.0	Not significant
nganese	92.4	87 to 95	Not significant
lcium	2.1[3]	2.1[3]	Not significant
uminum[2]	-	-	Not significant

[1]As determined by 95 pct. correlation coefficent of replicated samples and site numbers alyzed in order with site number

[2]No standard

[3]pct. by weight

Table 3 shows elemental levels for seven ecies of vegetation collected in the Great Smoky Mntains in the spring of 1978. Lead levels are hghest in moss samples. Copper levels tend to be hgher in wood fern and witch hobble, while mganese appears to be higher than previously reported for agricultural crops (Hemphill 1972). Hvever, Romney and others (1977) report manganese lvels for desert vegetation ranging from approxim:ely 20 ppm to 220 ppm. Van Hook and others (dated) report manganese values in chestnut oak a hickory on the Walker Branch water shed rging up to 1,000 ppm. Grodzinska (1978) rorted manganese levels in moss from Poland rged from 79 to 880 ppm. Therefore, the levels o manganese reported appears reasonable when cpared to other studies, particularly from fested areas. Calcium and phosphorus levels apear to be equal to or slightly below calcium lels reported for agricultural crops (Hemphill 12).

able 4 presents the results for the second spling that occurred in the fall of 1978. There w a large increase in lead levels in moss samples, but the rest of the vegetation samples reflected a slight decline in lead levels. A similar relationship was shown for copper.

Studies using vegetation, particularly for those elements where root uptake is small, as indicators of airborne pollution have ranged from interception phenomenon of vegetative surfaces for modeling purposes (Shreffler, 1978; Davidson and others 1976) to the use of individual species as collectors of airborne pollutants. Smith (1977) has reviewed the probability of urban vegetation filtering out airborne particulates. He reported that fine hairs on vegetative surfaces increase particle trapping phenomenon. Carlson and others (1976) and Wedding and others (1975) found in controlled studies that rough, pubescent leaves entrap seven times more particles than smooth nonpubescent leaves and the particle load increases with leaf area sometimes by a factor of 10. Removal of particle from vegetation surface appears to be through solubilization in rain and not physical impaction from droplets (Carlson and others 1976). Compounding this phenomenon is data reported by Harris and others (1976) which states "...all elements are in a far more soluble phase in the ambient aerosol (and are associated with particles retained by biological and inert surfaces) than in fly ash collected from in stack deflector plates...".

From the above discussion, plants with large leaf surface areas, or those with very rough pubescent surfaces (ferns, witch hobble) should collect larger particulate loads, but because of wash off, they probably cannot be expected to increase the particle load throughout a growing season unless another phenomena were at work. This is shown in table 4 by a decrease for lead and copper concentrations for ferns and witch hobble when compared to the results in table 3. Manganese, however, does not follow this pattern.

Tyler (1972) states that mosses, via passive ion exchange, can accumulate a variety of airborne elements. If this is the case then solubilization of surface material will not be an important removal process and fall moss samples should have higher levels than spring, particularly for copper and lead. Data in tables 3 and 4 tends to support this hypothesis.

The forest floor of the Great Smoky Mountains was sampled in the spring of 1978. Two types of samples were collected, the first was the unincorporated organic material and the second was the partially decomposed material of the fermentation layer. The results are shown in table 5. Except for manganese, significant differences existed between the litter and fermentation layer for all trace elements. The fermentation layer showed an increase in lead, copper, phosphorus, aluminum, and a significant decrease in calcium. Site to site correlations for each element, excluding aluminum, were significant between unincorporated organic matter and the fermentation layer.

Table 3--Average concentration of selected elements for samples collected in the Great Smoky Mountains biosphere reserve, spring 1978.

	Lead µg/g	Copper µg/g	Manganese µg/g	Calcium pct.	Phosphorus µg/g	Aluminum µg/g
Moss	42.3	13.4	368	0.32	1,430	1,410
Yellow birch *Betula alleghenies*is	12.2	13.2	2,090	1.38	2,540	165
Red maple *Acer rubrum*	3.8	9.0	597	0.51	2,320	94
New York fern *Thelypteris novaborecensis*	12.3	9.9	279	0.15	2,250	555
Wood fern *Dryopteris spinulosa*	16.0	29.0	382	0.09	4,940	210
Witch hobble *Viburnum alnifolium*	14.5	28.2	1,730	0.68	3,660	252
Fraser fir *Abies fraseri*	3.1	3.8	590	0.17	2,090	278

Table 4--Average concentration of selected elements for samples collected in the Great Smoky Mountains biosphere reserve, fall 1978.

	Lead µg/g	Copper µg/g	Manganese µg/g	Calcium pct.	Phosphorus µg/g	Aluminum µg/g
Moss	107.6	15.3	459	0.30	145	1,850
Yellow birch	5.1	10.5	2,370	1.50	2,360	154
Red maple	0.9	6.6	1,070	1.14	1,920	66
New York fern	9.9	3.9	1,000	0.68	854	2,040
Wood fern	5.3	11.5	1,350	0.50	2,200	424
Witch hobble	13.3	9.2	2,800	1.50	1,700	426
Fraser fir	0.2	3.8	915	0.30	2,680	375

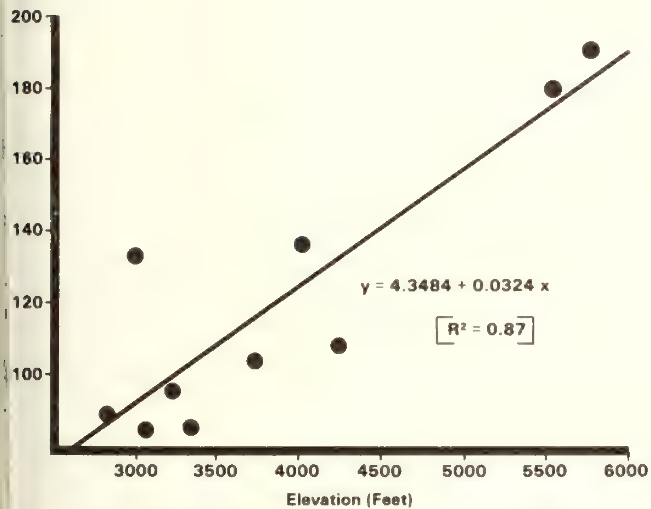
Reiners and others (1975) found lead levels in New Hampshire in litter increase with altitude. At extreme elevations, a slight decrease was noted. The levels of lead in litter ranged from 35 to 336 ppm. The fir forest sites had the highest lead concentrations. Figure 3 shows a similar relationship from our data for lead in the Smoky Mountains. This relationship did not exist for any of the other elements. Previous work by Wiersma and others (1978b, 1980) indicate that the probable source of this lead is from anthropogenic activities.

Some data are available from samples collected in the summer of 1979 in Olympic National Park. The forest floor was not sampled by the method previously used in the 1978 Smoky Mountains study. With the modified technique, unincorporated

able 5--Comparison of elemental levels in unincorporated organic material and the fermentation layer, reat Smoky Mountains biosphere reserve, spring 1978.

	Unincorporated organic material	Fermentation layer	T value[1]	Coefficient correlation (8 df)[2]
ead µg/g	37.8	83.7	9.6[2]	0.87[4]
opper µg/g	18.2	28.8	9.4[2]	0.80[4]
nganese µg/g	1,790	2,110	1.0 N.S.	0.77[4]
lcium pct.	0.89	0.58	-5.2[2]	0.92[4]
osphorus pct.	0.28	1.18	5.0[2]	0.73[3]
uminum µg/g	1,980	5,420	Not Calculated	

[1]Paired "T" test
[2]Element in unincorporated organic matter versus element in fermentation layer.
[3]95 pct. confidence
[4]99 pct. confidence



igure 3--Relationship between lead residues and titude in the Great Smoky Mountains Biosphere serve.

ganic materials were sampled along with the rmentation layer.

Copper and lead levels in moss and litter are mpared for the two biosphere reserves:

Comparison of moss samples from Olympic National Park and Great Smoky Mountains National Park. (µg/g)

	Copper	Lead
Moss-Olympic	4.4	5.7
Moss-Smoky Spring	13.5	42.4
Moss-Smoky Fall	15.3	108.0

Copper levels in moss in the Great Smoky Mountains average about 3 times greater than in the Olympic National Park. Lead levels in the Smoky Mountains are 7 to 19 times greater than the Olympic National Park.

A similar relationship exists for the forest floor samples:

Comparison of forest floor samples from Olympic National Park and Great Smoky Mountains National Park. (µg/g)

	Copper	Lead
Olympic litter	10.0	16.7
Smokys unincorporated organic matter spring 1978	18.2	37.8
Smokys fermentation spring 1978	26.2	83.6

True "background" levels for many trace elements are probably impossible to determine. Lead levels for moss in the Smoky Mountains appear high but in line with values reported in the literature. For example Ruhling and Tyler (1968) analyzed museum samples of moss. They found samples collected after 1950 had lead concentrations of 80 to 90 ppm. Samples collected around 1860 contained average lead levels of 20 ppm. These researchers believed that the 20 ppm level did not represent "natural" lead levels. They suspected "natural" lead levels might be considerably lower. The moss samples from Olympic

National Park averaged 5.7 ppm lead with some remote sites having average lead levels of 0.4 ppm and 2.2 ppm. Hirao and Patterson (1974) estimated for a remote site on the high sierra crest that 97 percent of the lead detected was from anthropogenic sources. Therefore, even for sites as remote as the high Dosewallips/High Quinault (over 13 miles from the nearest road) in a park that primarily receives wind off the Pacific Ocean, it may not be appropriate to consider the lead levels natural background levels.

It is our opinion that reference levels can be established in vegetation in remote areas for a variety of trace elements. Sites should be regionally representative and sampling should be repetitive through time, at least once a year, preferably twice a year. Biosphere reserves are ideal places to use because of their protected nature and the fact that they are selected to be representative of various biological systems.

Monitoring systems can and should be established in these reserves for the purposes listed.

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Effects of Chronic Exposures to Gaseous Pollutants on Primary Production Processes

Photochemical Oxidant Impact on Mediterranean and Temperate Forest Ecosystems: Real and Potential Effects[1]

John M. Skelly[2]

Abstract: Photochemical oxidants (primarily ozone) as air pollutants pose a more serious problem to forests of the United States than any other single air pollutant. Temperate and Mediterraean forests elsewhere have most likely been similarly impacted and current investigations of such effects are being pursued. Ozone (and its photochemically reactive precursors) has been demonstrated to occur at considerable distances downwind of major urban sources. Ozone has induced pertubations to vegetation over large areas and has therefore impacted innumerable and diverse forest ecosystems. Direct injury due to ozone has been documented to occur on numerous individual forest vegetation species but direct alterations of forest ecosystems as related to ozone induced effects have only been extensively documented in the San Bernardino Mountains of California; to a lesser degree similar studies have been done in the Blue Ridge Mountains of Virginia. Due to the current sulfur dioxide (SO_2) problems confronting European forests and due to the planned increased utilization of fossil fuels in much of the North American Continent, the influence of ozone in combination with SO_2 must be fully considered. The influence of other photochemical oxidants such as nitrogen oxides and peroxyacetyl nitrate on forest vegetation has remained relatively unknown.

The difficulty of understanding the real and potential impact of air pollutants such as ozone (O_3) on individual species within any given plant community as compared to relating direct or indirect effects of O_3 on entire and complex forest ecosystems must be several orders of magni- tude in difference. Several studies have relate dose effects to full-sib crosses of various forest tree species but such studies have listed a series of caveats for the reader to consider while interpreting even the most basic results obtained. Such caveats have taken into account possible unknown effects due to exposure chamber systems, physical and biotic factor interaction and/or related monitoring and data analysis methodologies. As research advances from studies of full-sib crossed plant materials through half sib (open pollinated, maternal lines) through species and forest types, to forest communities and complex forest ecosystems, the number of influencing variables to be considered while interpreting the results becomes disproportiona and difficult to comprehend.

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Most studies that have dealt directly with O_3 ;ects to any given plant species have not isidered the effects of pollutant combinations n at higher doses. Under natural conditions, est ecosystems are impacted by a multiplicity atmospheric depositions including anthropogenic lutants in gaseous, dry, and wet formulations. addition such depositions do not occur singly doses similar to those reported for various osure chamber studies, e.g., 1-8 hours per day 5 days/week for 10 weeks, but rather they ur at low concentrations, in various and stantly changing combinations and over ended exposure periods. Thus, ecosystem dies that have not considered even these few tors must be considered of limited value for intrinsic or extrinsic interpretation.

It is a well known concept that air pollutant ited pertubations lead to simplification of est ecosystems. Continued exposures to SO_2 plexes have resulted in simplification and ersal of once forested land to grassland munities or in some severe cases even to rility of the soil and accompanying erosion. ever, such severe impacts due to O_3 pollution e not been reported to occur with the possi- exception of major forest vegetation species line in the San Bernardino Mountains of thern California. The complexity of such plification scenarios involving minor changes receptor plant physiology and related long- n effects on competitive abilities such as roduction, nutrient cycling, and related food in events has not been well documented.

The main purpose of this paper is not to pre- : a review of literature pertaining to ozone ict to forest species and related ecosystems. eral excellent reviews of the subject have previously published and due to these compre- sive up-to-date analysis of the topic any her review would result in a redudancy in literature (Miller 1973; Miller and McBride); Brown and others 1979 and Kozlowski 1980). ier this symposium paper will attempt to relate e review articles and accompanying new liter- e into an analysis of the real and potential -term effects of ozone on forest ecosystems. tionally, an effort will be made to relate ting literature into suggestions for future ideration of ecosystem impacts into the onal Ambient Air Quality Standards.

ACKGROUND AND ANTHROPOGENIC CONCENTRATIONS OF OXIDANTS IN FOREST SITUATIONS

comprehensive review of ozone and other ochemical oxidants has been published by the onal Academy of Sciences (NAS 1977); a nt compilation of papers has also been ished (USEPA 1977b). These collective sets apers have provided an excellent review of origin, chemistry, transport, and atmospheric ling of these pollutants.

Background Concentrations

Ozone is a naturally occurring component of the Earth's atmosphere and concentrations of 0.03-0.05 ppm O_3 are generally considered to be normal due to mixing via the stratospheric transport effect (Corn and others 1975) (fig. 1).

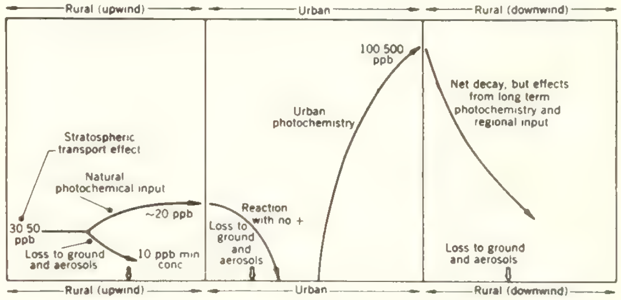


Figure 1--The tropospheric ozone cycle. (from Corn and others 1975).

The emission of oxidant forming precursors such as oxides of nitrogen and hydrocarbons into the lower atmosphere leads to the buildup of photochemically produced ozone and related peroxyacylnitrates (fig. 2) (NAS 1977).

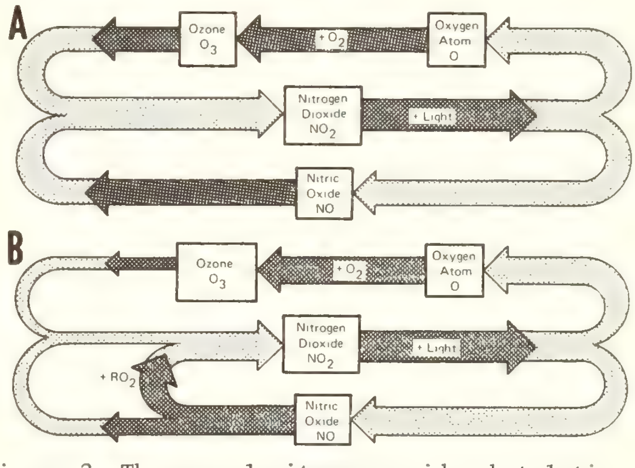


Figure 2--The normal nitrogen oxide phytolytic cycle (A) and the cycle as altered by the addition of hydrocarbons leading to increased ozone concentrations (B) (from NAS 1977).

PAN has not been detected in non-anthropogenically polluted atmospheres but oxides of nitrogen do occur naturally in the atmosphere and concentrations of 0.02-0.10 ppm NO_x have been reported (NAS 1977). Brennan (Personal communication) has reported a high PAN concentration in the Eastern United States of 10 ppb but suggested overall concentrations of PAN are well below West Coast observations.

Anthropogenic Concentrations in Forested Areas

The long distance transport of oxidant precursors and ozone into remote forested areas has

been well documented (Miller and others 1972; Husar and others 1977; Hayes and Skelly 1977; and Cleveland and Kleiner 1975). Concentrations of ozone above the current National Ambient Air Quality Standard (NAAQS) of 0.12 ppm O_3 one hour average per 24-hour period; twice (2 days) per year have recently been reported within the forested areas of Eastern (Skelly and others 1979) and mid-Western United States (Wolff and others 1977). Numerous reports of high ozone concentrations have been issued from the extensive San Bernardino Mountain Studies (SBM) in southern California (USEPA 1977a). Major episodes of ozone have developed sporadically over the summer months of May through October in eastern forests whereas a better defined and stable oxidant season exists in the forests of southern California. Galloway and Skelly (1978) defined a major air pollution epidose in July 1977 that involved high ozone concentrations and the highest ever recorded large and fine aerosol SO_4 concentrations (fig. 3, 4, and 5).

By comparing monitoring data from the SBM studies with those of the Blue Ridge Mountain Studies (BRM) a 3-4 fold greater concentration of ozone is apparent in the former over the latter. Peaks of 0.20 to 0.40 ppm O_3 daily one-hour maximums have occurred in the SBM forest (fig. 6) but the peak one-hour average ever recorded in the BRM area has been 0.166 ppm O_3. Table 1 presents the monthly and peak one-hour concentrations of ozone as monitored at various sites in the Blue Ridge Mountains of Virginia. PAN and NO_x have not been monitored in eastern forests of the United States and although detected in western forests little has been done to distinguish differences in their respective effects over those induced by ozone alone (fig. 6).

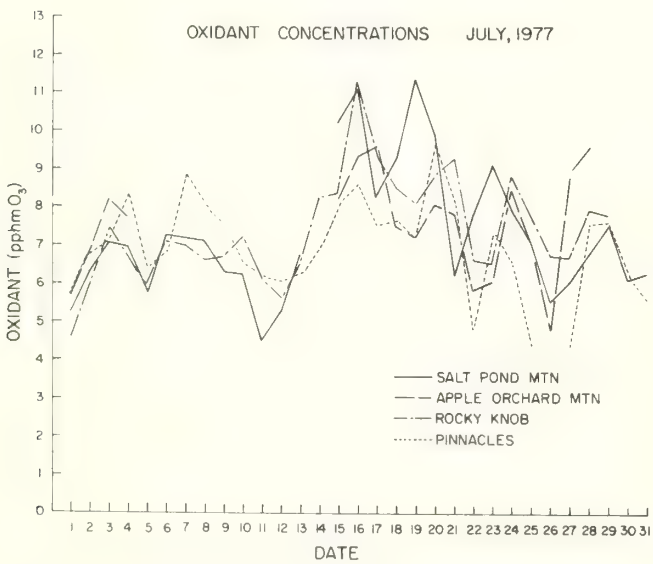


Figure 3--Oxidant concentrations as monitored at several locations in the Blue Ridge and Southern Appalachian Mountains of Virginia during July, 1977. Daily averages (24 hours) are indicated. Note peak period of July 15-20.

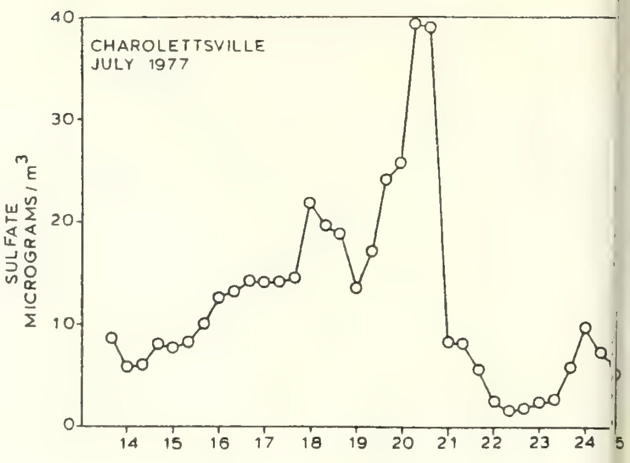
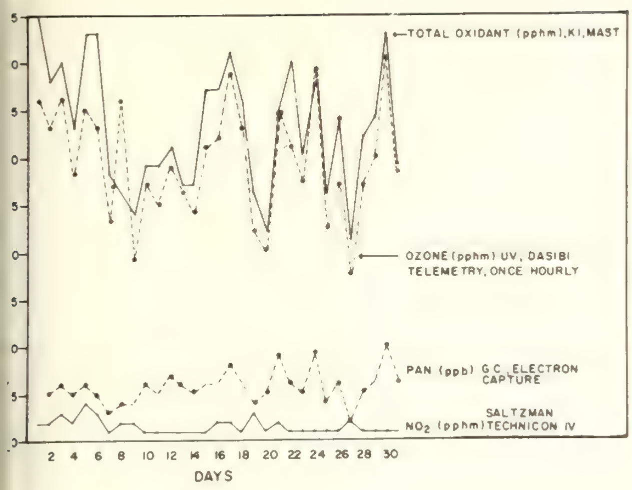


Figure 4--Total sulfate (mg/m^3) as monitored a Charlottesville, VA during air pollution episode of July, 1977. Note buildup of July 15-20 and similar sharp drop as in figure 3 on July. (from Galloway and Skelly 1978).

Figure 5(A)--A review of the Peaks of Otter a taken on a clear day in the Blue Ridge Mountains. Photograph taken from Pine Tree Overlook at a distance of 11.6 KM from the Peaks. (B) Photo taken on July 20, 1977 during the worst air pollution stagnation experienced in Virginia. Same view as (A).



igure 6--Comparative daily maximum hourly erages for ozone, total oxidant, PAN, and NO_2 Sky Forest August, 1974. (From USEPA 1977).

Ozone concentrations in European forests have t been extensively investigated but initial udies indicate that ozone appears to be episodal its occurrence in a manner similar to that perienced in Eastern United States. Grennfelt 979) reported on ozone concentrations as monitred at Rörvik about 40 KM south of Gothenburg, Norway; an area situated close to the coast and considered to be normally unaffected by local oxidant producing sources. The highest O_3 concentration observed at Rörvik was 0.20 ppm (August 1975) and in Gothenburg the highest O_3 concentration was 0.13 ppm (table 2). They suggested clockwise air movement as associated with high pressure systems and long distance transport from Europe to be related to the ozone episodes. Skarby (1979) reported that ozone values recorded in the summertime have been too high to be considered as normal background concentrations for Swedish conditions. During the summer of 1977 high O_3 concentrations (0.20 ppm) were recorded on 21 out of 92 days. She also suggested long-range transport to be involved.

From these few reports it is quite obvious that ozone concentrations in excess of the NAAQS occur frequently in the temperate and Mediterranean forests of the world. Therefore, it is also obvious that the injury thresholds for numerous plant species have also been frequently exceeded and the effects of these exposure doses are discussed below.

DIRECT EFFECTS TO FOREST SPECIES

The responses of any given forest ecosystem to

able 1--Ozone concentrations (ppm) monitored at Rocky Knob, Floyd Co., Va. (Blue Ridge Parkway) nd at Pinnacles and Big Meadows, Madison Co., Va. (Shenandoah National Park).

onth	1977				1978				1979			
	Rocky Knob		Pinnacles		Rocky Knob		Pinnacles		Rocky Knob		Big Meadows[1]	
	Month Aver.	Peak Hour Aver.	Month Aver.	Peak Hour Aver.	Month Aver.	Peak Hour Aver.	Month Aver.	Peak Hour Aver.	Month Aver.	Peak Hour Aver.	Month Aver.	Peak Hour Aver.
anuary	.035	.057	-	-	.024	.069	.032	.061	.033	.049	.042	.061
ebruary	.041	.088	-	-	.033	.063	.047	.074	.042	.084	-	-
arch	.046	.084	-	-	.048	.088	.052	.084	.057	.106	.059	.099
pril	.055	.102	-	-	.052	.093	.051	.085	.072	.128	.054	.100
ay	.054	.095	.051	.104	.060	.104	.059	.115	.065	.116	.048	.082
une	.051	.095	.057	.105	.068	.116	.073	.109	.071	.112	.051	.082
uly	.073	.166	.069	.120	.064	.099	.070	.116	.057	.114	.044	.094
ugust	.056	.092	.059	.104	.052	.093	.057	.103	.052	.085	.050	.072
eptember	.051	.100	.051	.097	.054	.092	.054	.100	.038	.072	.040	.095
ctober	.041	.072	.038	.072	.051	.105	.051	.114	.037	.074	.038	.082
ovember	.032	.061	.033	.067	.044	.103	[2].066	[2].091	.032	.062	.036	.072
ecember	.024	.044	.032	.052	.030	.050	.039	.049	.018	.046	.024	.045
verage or monitored mo.	.047		.049		.048		.054		.048		.045	

innacles site moved 14 KM to Big Meadow (SNP) May 1979.

nly 8 days out of the month were used for this data.

Table 2--The number of days with high ozone concentrations in Gothenburg and Rörvik, Norway 1972-1978 expressed as days with one hour mean of ozone exceeding indicated values (Grennfelt 1979).

Year	≥0.08 ppm	≥0.10 ppm	≥0.12 ppm	≥0.15 ppm	Max hourly mean (ppm)
Gothenburg					
1972	18	3	0	0	0.11
1973	12	1	0	0	0.10
1974	4	3	0	0	0.11
1975	13	1	0	0	0.10
1976	11	1	0	0	0.11
1977	9	1	1	0	0.13
[1]1978	8	6	2	0	0.12
Rörvik					
1975	-	18	11	5	0.20
1976	-	17	5	0	0.13
1977	-	6	0	0	0.11
[1]1978	-	12	8	1	0.15

[1]Includes data only until June 30, 1978.

photochemical oxidants must be as a result of the expression of direct effects to the individual component species within that ecosystem. The ability of scientific research to define those direct effects to individuals and to relate such defined effects to the whole has been limited. Three terms have been used somewhat interchangeably to define these effects and for purposes of this paper they shall be defined as:

Injury - the result of one or more deleterious alterations of normal physiological processes as manifested by the presence of chronic or acute visible symptoms and/or growth reductions (growth reduction may be the only manifestation).

Damage - injury that results in measurable economic loss to specific crops e.g. reduced height or radial increment growth of forest trees resulting in reduced value of the commerical forest.

Impact - the total influence (detrimental or beneficial) of air pollutants on all aspects of the forest ecosystem including even minor shifts towards reduced diversity of species, indirect effects to watersheds and water quality, or direct effects to recreational values due to reduced visibility at vistas or overlooks in National Forests and Parks.

Extensive research has been justifiably done on specific forest species to better define the injury phase of this scenario of increasingly inclusive terminology. However, even within th type of problem definition research a larger endeavor has been made to define visible plant responses over the less easily measured physiol-gical responses. The latter responses may actu-ly be of more importance to understanding the damage and impact phases of subsequent ecosyst deteriorations. Thus, three additional terms emerge:

acute injury - involves expresion of clinic symptoms leading to death of cells, tissues, organs, or entire plants and/or plant communit. Such injury is usually initiated by exposure t high doses of pollutants (>concentration x <ti but may result from exposure to lower concentr tions of pollutant over extended periods of ti.

chronic injury - involves non-lethal types clinical symptom expressions such as reduced chlorophyll production and related pigmentatio changes, and reduced growth rates. Such injur usually results from still lower dose exposure

functional injury - involves injury to the functional efficiency of the plant as express by reduced growth or other expression of loss

:hout the development of any other clinical nptoms, i.e. injury is only of a physiological il pre-clinical nature. Further visible nptoms do not develop. This form of injury is ;t difficult to define and measure and is the ;ult of lowest dose exposures at predominantly ır background concentrations of pollutants over :ended periods of time.

An attempt to define the current status of owledge concerning these various forms of di- :t effects due to ozone has been presented in ole 3. A more specific assessment of recent umented studies of chronic pollution effects induced by all species of air pollutants at the system level has been presented by Kickert and ler (1978).

It is evident from table 3 that our knowledge ozone effects following high dose exposures ng artificial exposure systems for species el investigations is considered somewhat erior to that of the other levels of activity. ever, when the abundance of plant species indigenous to a mixed hardwood-conifer forest ecosystem of the Northeastern United States is taken into account our knowledge is very limited even for the clinical expression of symptoms by most species. Interpretation of available knowledge in the forest community and forest ecosystem columns may be somewhat harsh but most probably realistic. A similar table as constructed for sulfur dioxide related investigations would be much more optimistic thus attesting to the relative ease of working on predominant point sources of pollutants and their related effects. However, our knowledge of SO_2 induced pertubations to forest ecosystems located at distances from various sources is relatively poor, e.g. knowledge of the subtle influences of S-related compounds to the productivity of Northeastern United States forests is virtually non-existent.

Direct Effects to Forest Trees

Davis and Wilhour (1976) have provided the most complete listing of woody plant sensitivities to sulfur dioxide and photochemical oxidants as

Table 3--The current status of knowledge concerning ozone induced effects to Temperate and Mediterranean forest tree species, forest communities, and forest ecosystems. Comparisons of the San Bernardino Mountain Studies (SBM) versus all other investigations (OI) have been noted.[1]

Effect	Study	Forest Species[2]	Forest Communities	Forest Ecosystems
Injury				
overall	OI	moderate	poor	poor
	SBM	moderate	moderate	moderate
acute	OI	abundant	moderate	poor
	SBM	abundant	moderate	moderate
chronic	OI	moderate	poor	non-existent
	SBM	moderate	moderate	poor
functional	OI	poor	non-existent	non-existent
	SBM	moderate	moderate	poor
Damage	OI	moderate	poor	non-existent
	SBM	abundant	moderate	poor
Impact	OI	3/	non-existent	non-existent
			moderate	poor

[1] In consultation by author with P. R. Miller (personal communication).

[2] Estimates in this column include responses obtained in fumigation chamber studies. If such information was to be detected poor to non-existent descriptions would be appropriate for each category.

[3] By definition not applicable.

derived from their review of United States, Canadian, and European literature.

Eastern White Pine

The predominant forest tree species studied in Eastern United States has been eastern white *Pinus strobus* L.; extensive literature reviews by Gerhold (1977) and Nicholson (1977) are available. Interest in this species has remained high since the first discovery of its somewhat unique sensitivity to ozone by Berry (1961). The response of this species to ozone concentrations as monitored in the Blue Ridge Mountains of Virginia (table 1) has been the subject of several current investigations. Skelly and others (1979) reported that of 315 white pines surveyed by using a modified evaluation scheme as adapted from Miller (1973) 17, 80, and 3 percent were considered to be tolerant, intermediate and sensitive, respectively, to ozone. Of the 315 trees tagged in 1977, 10 were reported to have died following repeated typical clinical symptoms of oxidant induced injury. Subsequent root excavations and isolation of fungi has yielded *Verticicladiella procera* from the dying trees. The growth rate of trees in each class was also examined by Benoit (1980) and radial increment growth over the period 1955-1978 for the sensitive class was significantly less ($p = .01$) than that of the tolerant class (figure 7). A general decline in growth for all classes was noted.

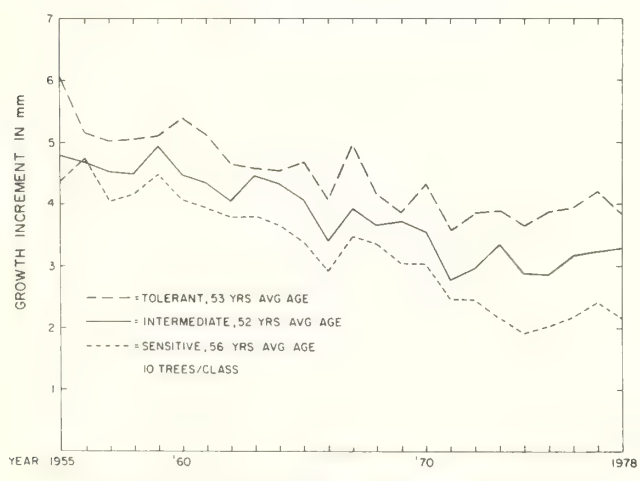


Figure 7--The average radial increment growth of eastern white pine in three ozone sensitivity classes as found in the Blue Ridge Mountains of Virginia. Trees were located in groups of 3 per site with each sensitivity class represented in each of 10 plots (10 trees/class).

Other Eastern Species

Forest trees--the relative O_3 sensitivity of species has been investigated using high dose exposures, e.g. 0.25 ppm O_3 for 8 hour exposure periods. Using such doses Davis and Wood (1972) exposed 18 conifer species and found Austrian Pine (*Pinus nigra*, Arnold), jack pine (*P. banksiana*, Lamb.) and Virginia pine (*P. virginiana*, Mill.) to be the most sensitive. However, they reported variable symptom response among the different species, among plants within species, and between branches and needles of individual plants. In a series of exposures, numerous deciduous trees were also exposed to similar ozone doses and green ash (*Fraxinus pennsylvani* Marsh.), white ash (*F. americana* L.) and tulip poplar (*Liriodendron tulipifera* L.) were report to exhibit foliar injury by Wood (1970). Jense (1973) determined the sensitivity of 9 deciduous tree species on the basis of height growth during a 5 month exposure to 0.30 ppm O_3 for 8 hours per day. He determined that silver maple (*Acer saccharinum*, L.), green ash, and sycamore (*Platanus occidentalis*, L.) were t only species determined to be sensitive using both parameters. Numerous similar studies usin high dose exposures have been reviewed by Skell and Johnston (1979).

Typical oxidant symptoms have been noted by Skelly (unpublished) on several major forest tree species indigenous to Shenandoah National Park of Virginia (fig. 8).

Figure 8--Typical oxidant induced stippling on hickory (*Carya* spp.) as observed in the Shenandoah National Park of Virginia. Note asymptomatic area of covered over portion of lower leaf in center of photograph (upper leaf pulled back).

Very few low dose exposure studies have bee conducted to determine effects due to closer t ambient pollutant concentration or due to amb exposure conditions. However, several recent studies have attempted to reproduce ambient concentrations of O_3, SO_2, and NO_x (and variou combinations thereof) and to study their effe on the growth of loblolly pine (*P. taeda* L.) Kress and Skelly (1980a) American sycamore Kress and Skelly (1980b), and several other eastern tree species (Kress 1980). In the com bined pollutant studies using 0.05 ppm O_3, 0. ppm NO_2, and 0.14 ppm SO_2 for 6 hours per day 28 consecutive days significant height reduct

e reported as induced by O_3 alone treatments each species without clinical symptoms pret on sycamore and with <5 percent foliar ury on loblolly pine. Kress (1980) reported ght growth increases and/or decreases for tree species following exposure to 0.05, 0, and 0.15 ppm O_3 for 6 hours/day for 28 secutive days. Lowest dose exposure signifitly reduced the height of loblolly pine and 0 ppm O_3 reduced height growth in loblolly pine, en ash, sycamore, pitch pine (P. rigida Mill.) sweetgum (Liquidambar styraciflua L.). ght height growth stimulations were reported several species following 0.05 ppm O_3 treatt and sugar maple (A. saccharum Marsh.) ponded positively even at the 0.10 ppm O_3 atment ($p = 0.05$).

Understory Vegetation--Harward and Treshow 71) have conducted one of few studies designed determine ozone effects to understory plants. y exposed 17 representative species of an en community to various high and low doses O_3 5 days per week throughout the growing son for 3 consecutive years. Several species found more sensitive than expected and sitivity was so varied between species that authors suggested major shifts in community position would be probable following only a year wo of exposure.

ohut and Krupa (1978) determined the sensity of several herbaceous plants of the Northral U.S. forests. They listed a group of ts found in the forests of the North Central on that were also sensitive to 0.08 and 0.15 O_3 for only 4 hours. These plants are also ve to the forested areas of the north and heastern portions of the United States. sensitive plants listed were wild buckt, chicory, daisy, mustard, and Ribes. r work by Skelly (1977, unpublished) has tified symptoms typically induced by O_3 on atis sp. in the Shenandoah National Park irginia.

igure 9 has been presented to further nstrate the effect of ambient concentrations zone on a species that is widely distritd across North America i.e. common milk- (Asclepias spp.). Duchelle and others 0) observed severe, moderate, and slight injury to this species that occurred rally in open plots and in non-filtered and ered open top chambers, respectively, as cted in the Shenandoah National Park in inia. This species is being tested further injury thresholds and for use as part of a t bioindicator system.

s another part of the Blue Ridge Mountain ies, Duchelle and Skelly (1980) established plications of open top chambers receiving coal filtered air or non-charcoal filtered in order to investigate height growth of cted forest trees. Four open plots were established. By mid-summer it became necessary to clip (to a 1.3 cm height) and remove competing natural vegetation which was then collected for dry weight measurements (table 4).

Figure 9--Oxidant injury to milkweed (Asclepias spp.) observed in the Shenandoah National Park, VA as grown in (A) open plots, (B) non-filtered open top chamber and (C) charcoal-filtered open top chamber. Purple stipple was only noted on upper leaf surfaces.

Table 4--The dry weight of foliage of composited clippings as collected from 4 filtered air and 4 non-filtered air open top chambers and 4 open plots established in the Big Meadows Area of the Shenandoah National Park, VA.

Exposure	Clipping Dates[1] Aug. 14, 1979 Dry Weight (Grams)		Oct. 9, 1979	
	Total wt[2]	Average	Total wt	Average
Filtered	7263	1816	1599	400
Non-filtered	4937	1234	1323	331
Open	3128	782	845	211

[1]All species composited as clipped to 1.3 cm height, 10 foot diameter plots.

[2]4 replications.

Western Species

Ponderosa Pine

Since the decline of ponderosa pine (P. ponderosa Laws.) during the 1950's (and henceforth into the 1980's) in the South Coast air basin and San Bernardino Mountains of California, this species has become the most intensively investigated of all western forest vegetation species. Declining ponderosa pines have most recently been reported in the southern Sierra-Nevada mountains by Miller and Millecan (1971) and in the Sequoia National Forest and Sequoia-Kings Canyon National Parks by Williams and others (1977).

The decline of this species was initially termed "X-disease" by Parameter and others (1962); further study by Miller and others (1963) elucidated ozone to be the direct incitant. Interrelationships of foliar symptoms with increased root disease and increased incidences of bark beetle infestations in injured trees have been determined along with significant growth decreases and mortality (Stark and others, 1968; McBride and others, 1975). Several reviews of the major studies that have dealt with ponderosa pine have recently been published by Brown and others (1979), Miller (1973) and Miller and McBride (1975).

Most recent investigations by Coyne and Bingham (in press) identified characteristics of ecotypic variation in P. ponderosa which varied in their clinical symptom response to ozone under field conditions. Light responses, photosynthetic rates, and stomatal conductances were observed and differences among injury classes were manifest as acceleration of the normal decline of CO_2 fixation and stomatal conductance usually associated with needle aging. Needles of sensitive trees senesced and abscissed prematurely thus contributing to a steady decline in tree vigor and increased vulnerability to other sources of stress.

Other Forest Tree Species

Miller (1973) ranked the following species fo[r] their decreasing sensitivity to ozone following fumigation tests:

Most sensitive	Western white pine (P. monticola Doug.)
	Jeffrey x Coulter pine hybri[d] (P. jeffreyi x P. coulteri)
	Red fir (Abies magnifica A. Murr.)
	Monterey x Knobcone pine hybrid (P. radiata x P. altenuata)
	Ponderosa pine (P. ponderosa Laws.)
Intermediate	Coulter pine (P. coulteri D. Don)
	Douglas fir (Pseudotsuga menziesii (Mirb.) Franco
	Jeffrey pine (P. jeffreyi Grev. & Balf.)
	White fir (Abies concolor (Gord. & Glend.) Lindl.
	Big cone Douglas fir (Pseudotsuga macrocarpa (Vasey) May.
	Knobcone pine (P. attenuata Lemm.)
Tolerant	Incense cedar (Libocedrus decurrens Torr.)
	Sugar pine (P. lambertiana Dougl.)
	Giant sequoia (Sequoia gigantea (Lindl.) Decne.

In one of few low O_3 dose exposure studies, 9 western conifer species have been evaluated for foliar injury and growth responses by Wilhour and Neely (1977). They found significant growth reduction in juvenile seedlings of P. ponderosa and P. monticola exposed to 0.10 ppm O_3 for 6 hours/day consecutively for up to 22 weeks. They noted no constant association between growth response and foliar injury.

DIRECT EFFECTS TO FOREST ECOSYSTEMS

A fair number of published reports assessing air pollution induced injury to agricultural cr[op]s are available. Damage estimates of yield losse[s] have also been published e.g. air pollution injury to potatoes in the Atlantic Coastal Stat[es] (Heggestad, 1973). Such evaluations have been based upon extensive knowledge of crop management practices and abundant information exists concerning expected yields. Therefore, yield

sses such as potato tuber number, size, and ight may be easily determined and subse- ntly correlated with the degree of foliar jury as induced by photochemical oxidants (ggestad, 1973).

Advancing from a relatively simplistic agro- nic monocultural system of crop management to mixed hardwood conifer forest ecosystem poses isiderably different problems in determining effect due to any given single stress factor. noted previously, an abundance of literature cribing symptoms has become available for eral major forest species that appear sensi- e to photochemical oxidants (table 3). How- r, the overall impact of the more subtle nges in functional efficiency of the plant ressed, for example, as slightly reduced photo- thetic capability of otherwise asymptomatic iage or noted trends of slightly shorter pollen e length in the presence of low doses of O_3 ain relatively little understood.

There have been no major investigations of dant impacts to forest communities or forest systems with the single well known exception the San Bernardino Mountain Studies. The ensity of the various studies and their ated interactions within one of many possible as of investigation has been illustrated in ures 10 and 11. As noted in figure 10, dant air pollutants are only one of many ural or anthropogenic stress factors important the forests of the San Bernardino Mountains if this figure were to be modified for illus- tion of an Eastern U.S. or European forest, and other forms of atmospheric depositions ld necessarily be added for emphasis. Figure illustrates only a few of the complex inter- ions which may take place within an ecosystem even a very subtle change in bark charac- istics or carbohydrate pools as initially iced by oxidant injury of the foliage may be ficient to encourage a bark beetle attack of kened trees. As related in table 3, an luation of knowledge concerning injury, age, and impact to forest species of the San ardino Mountains (primarily P. ponderosa) is dant and knowledge is considered to be erate for the forest community. However, due he complexity of any given forest ecosystem, luding that which has been intensively studied he San Bernardino Mountains, relatively poor rmation exists as to the subtle influences he functioning of any given forest ecosystem.

TURE RESEARCH EMPHASIS AND CONSIDERATIONS

hy do we know so little about oxidant induced ry, damage, or impact to forest communities orest ecosystems? Why have only a few tree ies been intensively studied and relatively others evaluated for foliar symptom response? does the lack of such information influence sions made regarding the establishment of onal Ambient Air Quality Standards?

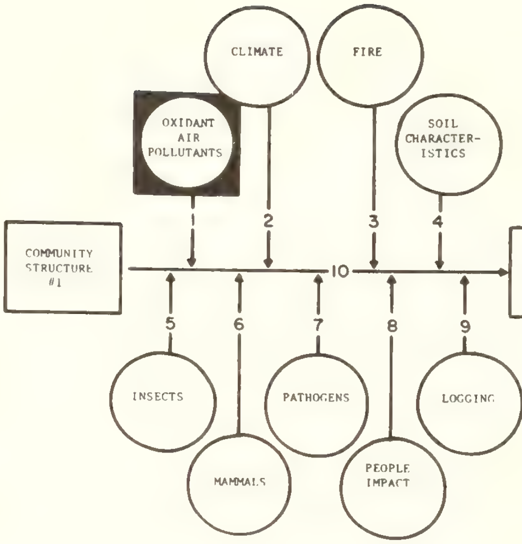


Figure 10--Community-succession interactions in a mixed-conifer forest ecosystem. (From Taylor, 1974).

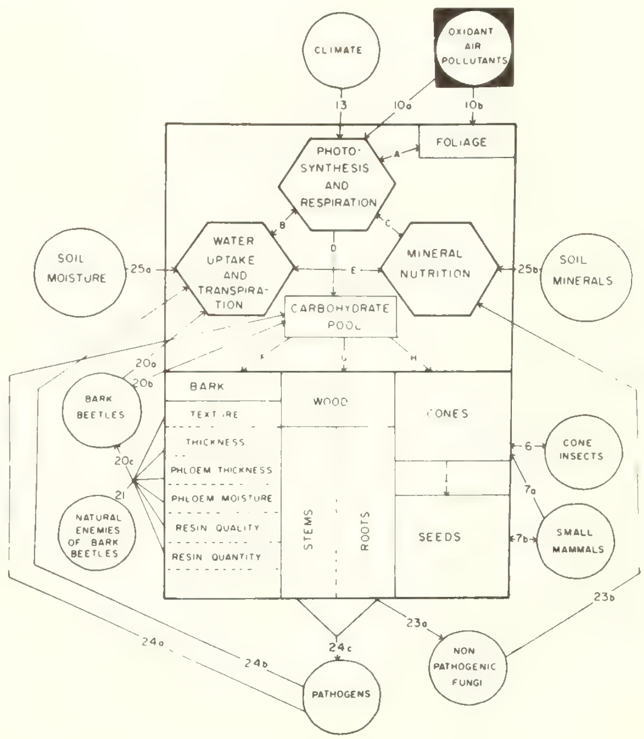


Figure 11--An example of tree-level interactions in a mixed-conifer forest ecosystem. Data from these types of studies would be integrated into overall effect illustrated in figure 11. (From Taylor, 1974).

Intensive management of agronomic crops through selection of tolerant varieties for planting in

high oxidant areas and appropriate changes in cultural practices such as withholding irrigation water during oxidant pollution episodes have all served to reduce the immediate injury (and therefore damage and impact) to such important crops as potatoes, tobacco, soybeans, snapbeans and certain horticultural plants. Through the development of such practices, the agricultural scientist has assisted the immediate grower (as should be the case) but concurrently the economic cost/benefit justifications for pollution abatement enforcement have been lessened since overall impact has potentially been greatly reduced. The evaluation of forest tree species for sensitivity to various pollutants has also been attempted and likewise long term growth losses may be averted. Such investigations must be approached with a certain degree of caution since long term subtle changes most undoubtedly are occurring in natural forest ecosystems but as yet most remain undetected. Natural ecosystems usually have a system of checks and balances but the system remains delicate and trends towards simplification are easily initiated. Changes in primary productivity, energy resource flow patterns, biogeochemical cycles, and species successional patterns may all be challenged by oxidant air pollution but have remained virtually non-studied.

The difficulties encountered in developing research aimed at isolating, identifying, and subsequently integrating the known effects of oxidant air pollutants on the forest ecosystem are too numerous to completely cover in the remaining space available. A partial listing however, must include these important points:

1) Photochemical oxidant is insidious over extremely large areas of diverse forest land and the establishment of control (non-pollution exposed) areas has become virtually impossible.

2) The introduction of charcoal filtration systems into such areas to establish "controls" is at best artificial and due to physical restrictions the ability of such systems to define a true ecosystem pertubation is likewise limited.

3) Long-term investigations must take into account innumerable variables some of which are very transient in their occurrence and others for which relatively little is known even under natural conditions.

4) Modeling and related statistical procedures must take into account the diversity and complexity of a forest ecosystem and statistically probabilities of $p = .01, .05$, or $.10$ must not be the only acceptable limits of "biological significance." The prediction of a biological event with 70 percent accuracy may be valid. Observation of only a 1-5 percent decrease in annual radial increment growth or similar decreases in pollen production and viability may not be statistically significant but may have greater long-term biological significance t[o] the ability of a species to survive over their natural range.

The natural forested ecosystems of the temper[-]ate and Mediterranean regions of the world may serve to provide the most invaluable bioindicato[rs] of long-term photochemical oxidant air pollution induced effects. National air quality standards must be reasonably developed to protect these natural resources from even minor change but initially adequate financial support and associated quality research must be continued to adequately define the real and potential effect of oxidants to plant species, to plant communities, and to entire forest ecosystems.

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Primary Productivity, Sulfur Dioxide, and the Forest Ecosystem: an Overview of a Case Study[1]

Allan H. Legge[2]

Abstract: The objective of the West Whitecourt case study was to determine the consequence of chronic long term exposure of a forest ecosystem to low concentrations of sulphur dioxide emissions originating from a "sour gas" processing plant in west central Alberta, Canada. An interdisciplinary ecological approach was utilized. The vegetation and atmospheric environment were characterized. A concept of ecologically comparable sampling site selection was developed and applied in the West Whitecourt study area. Laboratory and field measurements revealed a reduction in photosynthetic rate in lodgepole pine x jack pine (Pinus contorta x Pinus banksiana) in the field. Reduction of adenosine triphosphate (ATP) concentration in pine tissue during SO_2 fumigation in the field followed by complete recovery after termination of SO_2 fumigation and the disruption of mineral nutrient cycling in the forest ecosystem were observed. Basal area increment measurements of 200 lodgepole x jack pine trees from 5 ecologically comparable sampling sites revealed a decrease in wood production directly related to the presence of sulphur dioxide emissions. It is recommended that the concepts of the assimilatory capacity of the environment for sulphur gas pollutants and irreversible ecological modification be utilized as measures of environmental quality.

Many review articles have been written addres-g the problem of air pollutants and forest systems (Tamm and Aronsson, 1972; Smith, 1974; ler and McBride, 1975; and Linzon, 1978). se reviews documented the extreme examples of te high concentration long term air pollution ess on ecosystems and were essentially post-tem studies. Environmental change due to air lution stress was clearly visible in these es. With the exception of the San Bernardino ntain study investigating the effects of tochemical oxidants on a mixed conifer forest system in California (Miller and others, 1977; Kickert and Miller, 1979), very little emphasis has been placed upon integrated research programs concerning the impact of chronic long term low concentration air pollution stress on forest ecosystems. The objective of this paper is to present an overview of a four-year integrated forest ecosystem case study designed to determine the consequence of chronic long term exposure of a conifer forest ecosystem to low concentrations of sulphur dioxide emissions originating from a "sour gas" processing plant in Alberta, Canada (Legge and others 1978).

BACKGROUND TO THE CASE STUDY

Potential detrimental environmental impact of sulphur dioxide emissions from the sour gas processing industry upon the environment in Alberta was a major concern of this industry in the early 1970's. This concern lead to the formation of the Whitecourt Environmental Study Group (WESG) in 1971, a consortium of eight companies involved

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in the production of saleable natural gas from sour gas (natural gas containing hydrogen sulphide) in the Whitecourt district of west-central Alberta. It was clear at that time that the assessment of the impact of sulphur dioxide on the forest ecosystem was not a simple cause and effect relationship. A five-year environmental research program therefore was initiated in 1972 and was cooperatively funded by both industry and the Alberta Government. The objective of the research program which was called the Whitecourt Environmental Study was to determine the environmental consequences of the operation of sour-gas processing facilities on the forest ecosystem in the Whitecourt district occupied by 11 sour gas processing plants and defined as the Whitecourt study area (figure 1).

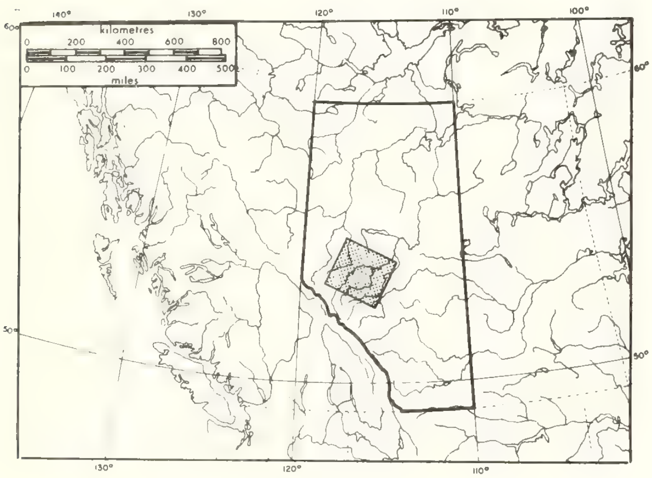

Figure 1. Map of western Canada showing in bold outline the province of Alberta and the Whitecourt Study Area.

The Whitecourt study began in 1972 as a remote sensing airborne environmental survey accompanied by assessment on the ground carried out by INTERA Environmental Consultants Limited to determine if there were any visible large scale environmental disturbances. After two years of general reconnaissance no large scale environmental disturbance was found (Whitecourt Environmental Study 1972 and 1973). Controlled SO_2 fumigation experiments carried out in the laboratory by the Kananaskis Centre for Environmental Research, University of Calgary, on young lodgepole pine (Pinus contorta Loud.) seedlings, however, revealed a direct effect of SO_2 on vegetation. These experiments showed that, although plants have the ability to adjust physiologically within certain environmental limits, plants were adversely affected when these limits were exceeded (Legge and Harvey 1974). A conflict therefore arose; the general environmental field survey indicated no large scale modification of the vegetation while the preliminary laboratory research indicated the potential for environment change in the field due to sulphur dioxide exposure. To resolve these contradictory research results it became clear that a detailed field case study of a forest ecosystem surrounding a sulphur dioxide source was required.

The AMOCO Petroleum Company Limited West Whitecourt (Windfall) sour-gas processing plant was chosen for the case study. This gas plant had the longest operational history in the Whitecourt study area beginning operation in 196

SOURCE OF SULPHUR GAS EMISSIONS

The following is a brief outline of the opera tion of the West Whitecourt sour-gas processing and sulphur recovery plant to familiarize the reader with the origin of sulphur gas air pollution from the sour-gas processing industry in Alberta.

Hydrogen sulphide is the principle sulphur co pound present in sour natural gas and is remove by a series of chemical processes in a sulphur recovery gas plant as elemental sulphur. The H_2 not converted to elemental sulphur is incinerate in a high temperature reaction furnace (580^{o} Celcius) in excess air and methane where it is oxidized to sulphur dioxide (SO_2) and vented to the atmosphere from a tall (122 meter) "candy-striped" incinerator stack. In addition to an incinerator stack, smaller stacks called flare stacks, generally less than 46 meters in height,

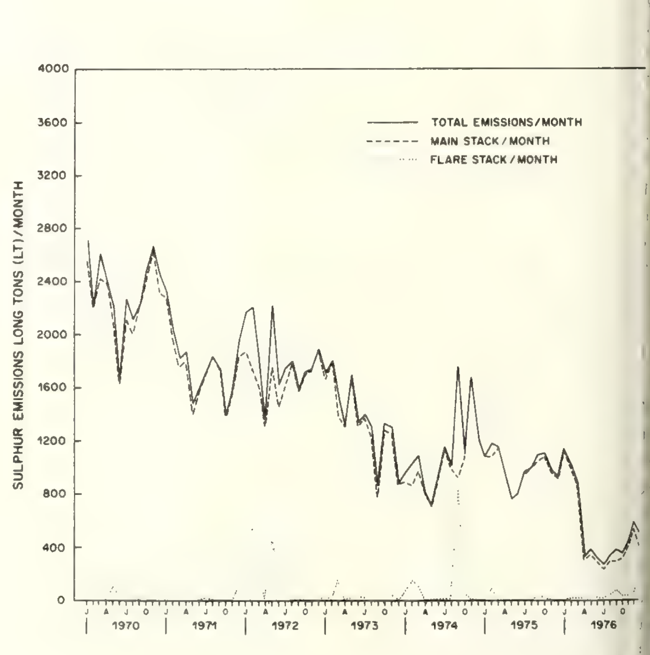

Figure 2. Monthly sulphur emission history of the West Whitecourt Gas Plant from 1970 through 1976.

e used to burn small waste quantities of lphur recovery gas plant process and compressor ses. Except in the case of a gas plant operaonal upset, when for short periods the flare ack may contribute more sulphur gas emissions the atmosphere on a daily basis than the innerator stack, the incinerator stack is the in source of sulphur gas emissions from the st Whitecourt Plant.

The monthly sulphur emissions (in long tons) the West Whitecourt Gas Plant for 1970 through 76 is shown in figure 2; simply double the lphur emissions to obtain the SO_2 emissions. is important to note that this gas plant has luced its sulphur emission output per day an ler of magnitude since start-up in 1962 from) long tons/day to 18 long tons/day in 1976. s reduction was achieved by enhanced operating cedures and the addition of "tail-gas" reery units.

SULPHUR: THE NUTRITIONAL CONTROVERSY

Sulphur is an essential nutrient element for mal plant growth and metabolism. It is rered in intermediary metabolism and is a contuent of many organic compounds such as amino ds and proteins in plant tissue. Sulphur mally enters the plant via the root system in form of sulphate, which is biochemically reed and then converted into numerous organic pounds. Plants, however, can also take-up utilize SO_2 from the atmosphere via the nates and utilize it as sulphur source for nt nutrition. Faller (1971), for example, has wn that tobacco plants can utilize SO_2 as a rce of sulphur in sulphur deficient soils. s type of information has led many government industry departments to say that SO_2 emitted n industrial sources is actually beneficial as erial fertilizer for plants growing on sul- deficient soils (Terman 1978; Noggle and s 1979). The situation is not quite so le, however. Though a small amount of atmos- ic SO_2 can be nutritional to plants in the t term, the large amount and high frequency ncontrolled application of sulphur such as to an ecosystem by sulphur sources such as ters, pulp and paper mills, coal-fired power ts, oil sand and oil shale extraction plants sulphur recovery gas plants can be detrial in the long term. Different plant species only have different nutritional requirements sulphur, but the rate at which plant species milate sulphur is influenced by many other ables, such as physiological status, age, during the growing season, temperature, nutrient availability, and light intensity ame a few. When more sulphur is available can be assimilated it is accumulated in the ue (Ulrich and others 1967; Legge and others ; Cowling and Koziol 1978; Thompson and Kats). This foliar sulphur accumulation can n toxic levels and adversely affect plant growth (Katz 1949; Linzon and others 1978). The distinction between the assimilation and the accumulation of sulphur of atmospheric origin by plants must be addressed in any ecosystem study.

CONCEPTUAL APPROACH TO CASE STUDY

To carry out an ecosystem case study one must have a basic understanding of what an ecosystem is. The ecosystem is the basic functional unit of ecology since it includes both the living organism and the non-living environment in which these organisms live. Odum (1971) has defined an ecosystem as "any unit that includes all of the organisms in a given area interacting with the physical environment so that a flow of energy leads to clearly defined trophic structure, biotic diversity and material cycling within the system". Due to the inseparable nature and interdependence of the components of ecosystems upon one another, however, any change that occurs in one component of the ecosystem potentially affects all the components of that ecosystem. The higher the diversity of an ecosystem therefore the more numerous the interrelationships within the ecosystem (Jernelou and Rosenberg 1976). The stability of an ecosystem can be viewed as a function of the balances amongst the components of that ecosystem. An environmental stress such as air pollution can modifiy the stability of an ecosystem by disrupting the balance amongst the ecosystem components.

Prior to the initiation of the West Whitecourt case study, it was recognized that an ecosystem study was an interdisciplinary undertaking. The term interdisciplinary in this context means the amalgamation of a set of specific disciplinary talents to work together to address a complex environmental problem. An interdisciplinary research team was assembled by the Kananaskis Centre for Environmental Research of the University of Calgary, The University of Alberta, The University of Washington, San Jose State University and the Southern Alberta Institute of Technology. The scientific expertise of the research team was broadly based and ranged from remote sensing, ecology, taxonomy, genetics, plant physiology, analytical chemistry, biochemistry, stable isotope physics and meteorology to statistics and electrical engineering.

A conceptual model was developed to illustrate the dynamic relationship between the sulphur dioxide "source" and the generalized ecosystem "sink" and is shown in figure 3. For purposes of communication among disciplines, the ecosystem was sub-divided into the following four compartments: air, vegetation, soil, and water. The two-way arrows indicate the inter-relationship of the four ecosystem compartments. The expertise of each member of the research team was thus focussed on more than one of the ecosystem compartments at all times. This lead to the formulation of cooperatively designed experiments to evaluate not

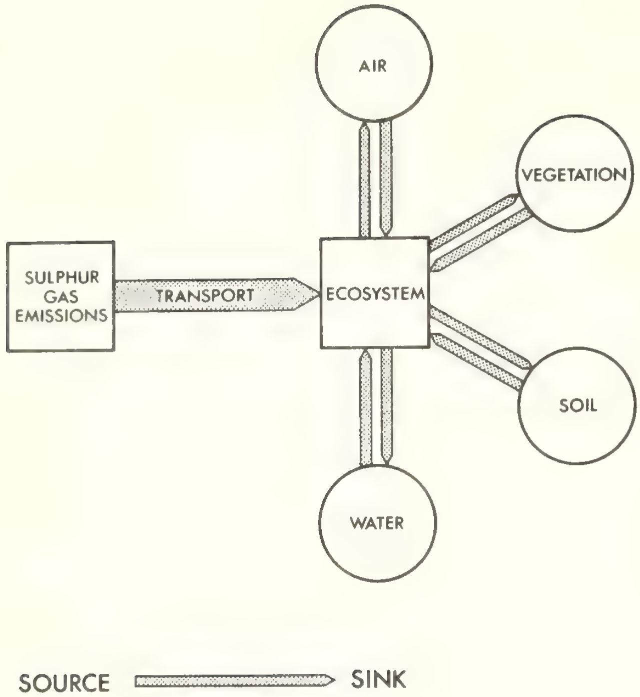

Figure 3. Conceptual model of the forest ecosystem in the West Whitecourt case study area.

only the interfaces between ecosystem compartments but also the processes within the ecosystem compartments. Scientists with different areas of expertise were brought into the case study, however, as a function of the needs of the research program. The selection and the timing of interaction of disciplinary participants were viewed as critically important factors for the success of the program so the case study grew in terms of disciplinary participation from 7 in 1974 to 10 in 1975 and finally to 12 in 1976 and 1977. This evolutionary interdisciplinary approach added a dimension of insight into the fate of sulphur gas emissions in the forest ecosystem that would not have been possible had the separate disciplines of the research team been operating in isolation.

VEGETATION CHARACTERIZATION

The vegetation of the Whitecourt area is included in the predominately forest subregion of the Boreal Forest Region of Canada (Halliday 1937) and is characterized as a transition forest area between the Boreal and Subalpine Forest Regions. The transitional nature of the common species of trees occurring in the area are actually represented by populations of hybrid individuals between lodgepole pine (Pinus contorta Loud.) and jack pine (Pinus banksiana Lamb.), while the true fir in the area represents hybrids between alpine fir [Abies lasiocarpa(Hook.) Nutt.] and balsam fir [Abies balsamea (L.) Mill.] (Legge and oth[ers] 1977).

A physiognomic classification of the vegeta[tion] communities in the West Whitecourt study area identified 13 major cover types out of 24 community types. Ten climax vegetation associati[ons] were recognized. The vegetation of the study area was mapped using a combination of LANDSAT imagery, LANDSAT digital data and conventional false colour infrared aerial photography both which were accompanied by ground based verific[a]tion. With the aerial colour infrared photography of the West Whitecourt study area a subsample, computer mapping utilizing LANDSA[T] digital data was completed on 116,000 hectares [to] place the study area in a regional perspective The computer mapping of the study area was eig[ht] times faster than conventional photography alo[ne] and had a comparative accuracy of 93 percent.

ECOLOGICALLY ANALAGOUS SITES

One of the principle difficulties encounter[ed] by air pollution researchers, before collectin[g] samples in the field for analysis, is the sele[ction] of sampling locations. Most sampling location[s in] air pollution studies are chosen solely on the basis of a gradient which is usually a functio[n of] the prevailing wind and the distance from a po[ll]ution source. Not enough emphasis is placed u[pon] the structure and composition of the plant com[muni]ties from which samples are taken. Since an e[co]system is composed of many interrelated highly variable biological and physical components, t[he] response of these components to a chronic envi[ron]mental stress such as air pollution will also [be] highly variable. If the range of variability [in] responses of ecosystem components to an enviro[nmen]tal stress is not considered, the expression o[f] the effect of the environmental stress on the [eco]system components may not be detected. There [must] be a common basis for comparison of ecosystem [com]ponents therefore to determine both the gross [and] subtle effects of an environmental stress alon[g a] gradient.

The concept and criteria for ecologically analogous sample site selection were developed and applied during the West Whitecourt case st[udy] in an attempt to minimize the variability of e[co]system components and hence to minimize the va[ria]bility of the response of the ecosystem compon[ents] to air pollution stress. The key to this conc[ept] of sample site selection is based upon compara[ble] ecological variability of the ecosystem compon[ents] and comparable environmental variability at the sampling locations chosen along a dista[nce] gradient. The criteria for ecologically analo[gous] sample site selection are summarized in Figure When the ecological and environmental variatio[n] of ecosystem components at all the sampling lo[ca]tions are as similar as possible, the sampling sites are said to be ecologically analogous. major difference amongst the sampling location

ECOLOGICAL ANALOGUE CONCEPT

ASSUMPTIONS $1 \equiv 2 \neq 3$

1. **Ecological Variables (sites $A_1 \rightarrow A_n$)**
   - slope
   - aspect
   - soil type
   - soil moisture
   - species density
   - species diversity
2. **Environmental Variables (other than pollutants)**
   - temperature
   - wind
   - solar radiation
   - precipitation
3. **Pollutant Variables**
   - composition
   - location
   - distance
   - concentration/conversion
   - frequency/duration

$$[SO_2]_{A_1} > [SO_2]_{A_2} > [SO_2]_{A_3} > [SO_2]_{A_4} > [SO_2]_{A_5} \cdots > [SO_2]_{A_n}$$

Figure 4. Summary of criteria utilized for the selection of ecologically analogous sample sites.

therefore is distance from the pollution source. The assumption is that the pollutant variables such as concentration, frequency of fumigation and duration of fumigation will decrease in magnitude with increasing distance from the pollution source. The magnitude of the air pollution stress on ecosystem components at the sampling locations will correspondingly decrease with increasing distance from the pollution source. This procedure ensures that the expression of the air pollution stress on ecosystem components will be maximized.

Meteorological and air quality data were essential in sample site selection. The prevailing winds during the growing season in the study area were shown to have the highest frequency of occurrence from the WNW and the second highest frequency from the ESE. Sulphur dioxide emissions from the West Whitecourt Gas Plant therefore occurred with greatest frequency in a WNW⇄ESE corridor. Although idealized, the corridor concept provided an essential point of reference for the areas chosen for the selection of sampling locations in the West Whitecourt study area.

The range of distances at which maximum ground level concentrations would occur from sulphur gas emissions from the main incinerator stack and flare stacks was calculated using the simple Gaussian plume model under mean wind conditions and a wide range of stability classes. The maximum ground level concentrations would occur between 1.6 and 34.0 km downwind of the incinerator stack and between 0.4 and 2.6 km downwind of the West Whitecourt Gas Plant. The intensive experimental site therefore, was principally exposed to sulphur gas emissions from the flare stacks. Only under short-lived meteorological conditions such as would occur during the break-up of an inversion would sulphur gas emissions from the main incinerator stock reach the intensive experimental site.

It must be emphasized at this point that the air quality standards for SO_2 of 0.2 ppm/½ hr./24 hr. as set by the Alberta Department of the Environment, were only exceeded on three occasions at the intensive experimental site 1.5 km east of the West Whitecourt Gas Plant in over 2500 hours of ambient air monitoring during the 1975 and 1976 growing seasons in the West Whitecourt study area.

Five ecologically analogous lodgepole x jack pine sampling locations were selected in the West Whitecourt case study area. The five sample sites were chosen in locations which were progressively downwind in the main path of sulphur dioxide emission corridor. These sites were chosen in this manner so that the sulphur dioxide emission impact gradient would be very steep across the five sampling locations to maximize the differences in the responses of the ecological analogues to pollution stress. The conceptual ecological model presented in Figure 3 can be generalized to express the relationships amongst the five ecological analogues and is shown in Figure 5. The ecologically analogous sampling

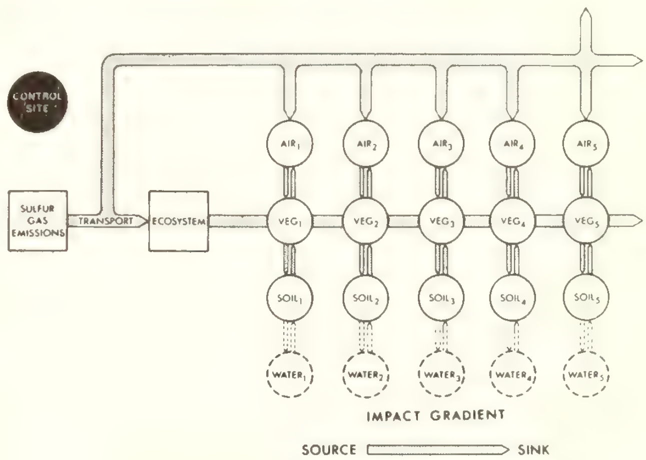

Figure 5. Replicated conceptual ecological model illustrating the five ecologically analogous lodgepole x jack pine sampling locations along a sulphur dioxide concentration gradient.

sites were located at distances of 1.2 km (A_I), 2.8 km (A_{II}), 6.0 km (A_{III}), 7.5 km (A_{IV}) and 9.6 km (A_V) from the Gas Plant. Sampling locations in the study area other than ecological analogues were designated by the letter S.

CASE STUDY DATA OVERVIEW

Foliar sulphate-sulphur concentration in lodgepole x jack pine trees was found to be a better measure of foliar sulphur accumulation than the foliar total sulphur concentration. The method of Johnson and Nishita (1952) was used to determine foliar sulphate-sulphur concentration while a Leco Furnace was used to determine foliar total sulphur. Figure 6 shows a plot of foliar sulphate-sulphur concentration in age-classed lodgepole x jack pine

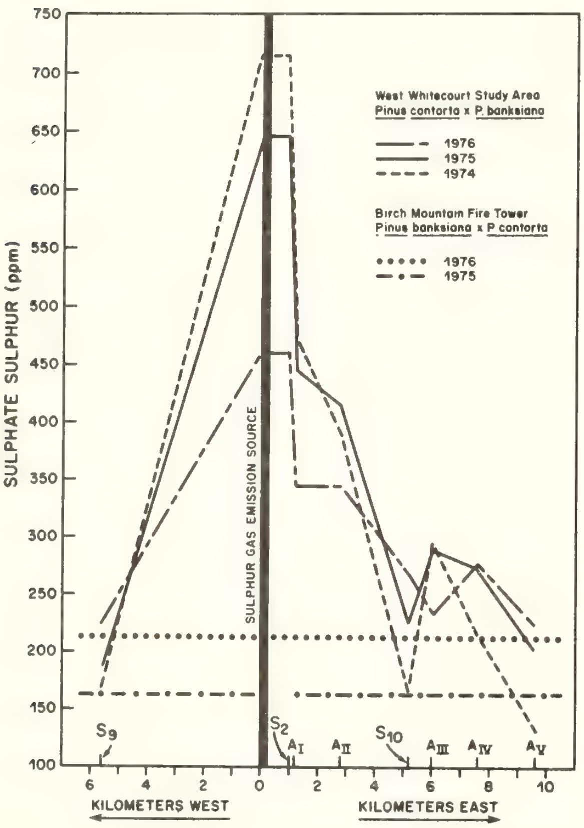

Figure 6. Plot of foliar sulphate-sulphur concentration in age-classed lodgepole x jack pine foliage from eight sampling locations in the West Whitecourt study area as a function of distance from the West Whitecourt Gas Plant.

foliage as a function of distance from the West Whitecourt Gas Plant. The background foliar sulphate-sulphur concentration was determined from age-classed foliage of jack pine x lodgepole pine from the Birch Mountain Fire Tower 111 km (69 mi) NNW of Fort McMurray, Alberta. One can clearly see the decrease in foliar sulphate-sulphur concentration with increasing distance from the sulphur gas emission source. The decrease in foliar sulphate-sulphur concentration with distance was more pronounced with increasing foliar age. The foliar sulphate-sul data strongly support the concept of an enviro mental stress gradient presented earlier.

The stable sulphur isotopic composition (S^{32} S^{34} ratio) of sulphur dioxide emissions from so gas plants in Alberta have been shown to differ from the natural environmental background stabl sulphur isotopic composition (Lowe and others, 1971; Krouse, 1977). This is referred to as th $\delta^{34}S$ value. The more positive the $\delta^{34}S$ value t greater the enrichment in S^{34}. The background stable sulphur isotopic composition in the West Whitecourt study area is near 0.

The stable sulphur isotopic composition of sulphur dioxide emissions from the incinerator stack at the West Whitecourt Gas Plant was show to be +22.2°/₀₀ (per thousand). This differenc provided an environmental tracer for sulphur of industrial origin.

The mean $\delta^{34}S$ value of 1974-1976 foliage fr the ecologically analogous sampling locations A_I through A_V remained close to the mean $\delta^{34}S$ value for the incinerator stack at +22.2°/₀₀ while the mean foliar sulphate-sulphur concentr tion in 1974-1976 foliage decreased from 422 pp to 185 ppm. These data clearly show that lodge pole x jack pine trees were obtaining some of their sulphur directly from the atmosphere from sulphur gas emissions originating from the West Whitecourt Gas Plant. Needles in the upper cr of many lodgepole x jack pine trees in the West Whitecourt study area, however, displayed folia $\delta^{34}S$ values which were greater than those associated with incinerator stack emissions. These data when compared to the laboratory data of Wilson and others (1978) was suggestive of isotopically selective metabolic processes functi ing in the lodgepole x jack pine foliage unde field conditions .

The 28-meter radio mast tower erected at th intensive experimental site provided a framewo for measuring and characterizing SO_2 concentrat profiles of ambient air above, within and belo the lodgepole x jack pine forest canopy. The vertical SO_2 profiles revealed that the SO_2 concentration minimum measured in the upper cr at 16 meters was primarily due to an aerodynam effect and was not due to the trees acting as biological sink. This aerodynamic effect was described as a splitting of the air flow above and below the crowns of the lodgepole x jack p trees. The measurements of foliar sulphate-sulphur, foliar total sulphur and foliar $\delta^{34}S$ values revealed that the trees, however, were also a biological sink for sulphur gas emissio but that the rate of atmospheric sulphur uptak by the trees was so slow that it was beyond th resolution of the two Thermo Electron Model 43 Pulsed Fluorescent SO_2 analyzers used.

Photosynthetic rates and leaf resistances o lodgepole x jack pine trees in the West Whitec study area were shown to be modified. The amo

this ecological modification was a function of e distance from the West Whitecourt Gas Plant. r example, the seasonal photosynthetic rates of 76 lodgepole x jack pine foliage were lower and e leaf resistances higher when foliage from (1.5 km east) was compared with foliage from $_0$ (5.2 km east) (4.38 ± 1.99 mg CO_2/dry g/hr rsus 6.42 ± 1.28 mg CO_2/dry g/hr and 11.3 ± 6 s/cm versus 7.8 ± 1.9 s/cm for sample sites and S_{10} respectively). This relative reducon in photosynthetic rates, however, was only rtially attributable to increased leaf restance. Additional ecological factors therere, such as foliar mineral nutrient status d soil pH were considered since these paraters were known to modify plant response.

A detailed analysis of foliar mineral nutrient ncentration of N, P, K, Ca, Mg, Mn, Al, Fe and in lodgepole x jack pine foliage from nine mpling locations (including the ecological alogues) in the West Whitecourt study area vealed that the mineral nutrient status of lodgepole x jack pine trees had been altered. must be remembered at this point that normal nt growth requires a balance of all essential eral nutrients within the plant. The foliar centration of P, K, Fe, Mg, N and Zn tended increase while the foliar concentration of and Al tended to decrease with distance from West Whitecourt Gas Plant and distance from WNW⇄ESE sulphur dioxide emission corridor. e type was shown to be a critical factor luencing the concentration of these eight eral nutrients. Foliar Mn concentration was nd to decrease dramatically with distance from West Whitecourt Gas Plant and distance from WNW⇄ESE sulphur gas emission corridor. iability of site type, however, did not ify this relationship. A low Fe to Mn ratio found in foliage from sampling locations hin 4 km of the West Whitecourt Gas Plant. low foliar Fe concentration may contribute the chlorotic appearance of the foliage at se locations. Foliar mineral nutrient analysis foliage S_2, S_5, A_I and S_{10} revealed that foliar d P were lower in concentration in foliage n S_2, S_5 and A_I than from S_{10}.

Since foliar K concentration has been linked stomatal activity, the reduced foliar K entration may be inhibiting stomatal opening increasing leaf resistance which would then t photosynthetic rate. Reduced foliar P entration may inhibit phosphorylation and eby also limit photosynthetic rate. Foliar ient deficiencies of either P and K alone or ombination therefore may be partially responle for the reduced photosynthetic rates obed in lodgepole x jack pine foliage in the Whitecourt study area.

he alteration of foliar mineral nutrient us in lodgepole x jack pine trees in the Whitecourt study area therefore is an rtant ecological factor contributing to modification of plant response.

Soil pH profiles were measured at the same nine vegetation sampling locations where foliar mineral nutrient concentrations were determined since soil pH is known to affect the availablility of mineral nutrients to plants. The general trend or gradient in soil pH over all nine sampling locations was an increase in soil pH with depth and with distance from the West Whitecourt Gas Plant and distance from the WNW⇄ESE sulphur gas emission corridor. The soil pH gradient was most striking when only the ecologically analogous sampling locations were considered. A direct relationship was found between lowered soil pH and the elevated levels of foliar Mn in lodgepole x jack pine trees. The foliar Mn concentration data and the soil pH data suggest that foliar Mn concentration in lodgepole x jack pine trees could be used as a mineral nutrient indicator of modification of the forest ecosystem by sulphur gas emissions.

Soil total sulphur concentration in the soil profiles at the nine soil sampling locations also decreased with soil depth, distance and direction from the West Whitecourt Gas Plant. It is important to note, however, that there was no correlation between soil total sulphur concentration and soil pH. There was also no direct correlation between a given soil pH value and the soil $\delta^{34}S$ value. These data suggest that the soil $\delta^{34}S$ value can be used as an indicator of the presence and penetration of sulphur gas emissions into the soil profile while soil pH and soil total sulphur can be used as indicators of sulphur loading of the soil.

In terms of plant biochemistry and sulphur gas emissions the most significant observation in the field was a transient metabolic effect; the ATP (adenosine triphosphate) concentration of foliage cells from lodgepole x jack pine trees was found to be directly decreased upon exposure to low concentration short duration SO_2 fumigation (75% decrease upon fumigation with 0.14 ppm SO_2 for 15 minutes). It is important to note that when the foliage was no longer exposed to SO_2 the foliar ATP concentration increased to the pre-SO_2 fumigation ATP concentration (see Harvey and Legge, 1979, for details). This decrease and increase in the foliar ATP concentration was also observed with excised lodgepole x jack pine branches from the West Whitecourt study area which were fumigated under controlled conditions at the Kananaskis laboratory. When lodgepole x jack pine trees, which had been grown in the absence of sulphur gas emissions in the laboratory, were fumigated with SO_2 no fluctuation in ATP concentration was observed. It is important to note that the laboratory trees had a foliar ATP content which was over twice the foliar ATP content of the lodgepole x jack pine foliage from the West Whitecourt study area (658 nmoles/dry g versus 1460 nmoles/dry g). The lower foliar ATP concentration of field grown trees compared to laboratory grown trees suggests a partial explanation for the lowered photosynthetic capacities reported for lodgepole x jack pine trees in the West Whitecourt study area.

The photosynthetic rate of lodgepole x jack pine trees grown under controlled conditions in a non-SO_2 environment in growth chambers at the Kananaskis laboratory and lodgepole x jack pine trees grown in the sulphur dioxide emission environment in the field at the intensive West Whitecourt study site S_5 was measured when both sets of trees were exposed to similar low concentration short-duration SO_2 fumigations. The photosynthetic rate of the field grown plant material was not depressed by SO_2 fumigation while the photosynthetic rate of the laboratory grown material was depressed by the SO_2 fumigations. The photosynthetic rate of the laboratory trees was much greater than the trees in the field. There was also no evidence of a plant-water deficit in lodgepole x jack pine trees severe enough to effect photosynthetic rate.

Adenosine triphosphate is the major biochemical intermediate of energy transfer in biological systems. A decrease in foliar ATP content in lodgepole x jack pine trees caused by SO_2 fumigation therefore would also be a decrease in the amount of biochemical energy available for normal metabolic functions. Although the ATP content of the lodgepole x jack pine foliage recovered to the pre-SO_2 exposure concentration after the SO_2 stress was removed, during the SO_2 fumigation there would have been a net loss of biochemical energy. The fact that foliar ATP content increased after SO_2 fumigation, indicated that the trees were coping with the sulphur gas emissions at the cost of a metabolic energy drain.

In summary, the contrast in the biochemical and physiological responses of the lodgepole x jack pine trees fumigated with SO_2 in the field and the laboratory strongly indicates that environmental pre-history and acclimation of the trees to ecological modification of components of the forest ecosystem are the critical factors determining plant response to sulphur gas emissions in the West Whitecourt study area.

A comparison of the mean photosynthetic capacities of 1976 lodgepole x jackpine foliage through the 1976 growing season at sampling locations S_2, S_5 and S_{10} revealed that S_{10} had a positive net CO_2 fixation balance two to three weeks prior to the foliage at S_2 and S_5 and is shown in Figure 7. The mean photosynthetic capacity of 1976 S_{10} foliage was also always higher than the mean photosynthetic capacity measured for 1976 foliage from S_2 or S_5 . Additionally in terms of photosynthetically active needle biomass lodgepole x jack pine branches sampled at S_1, S_2, A_I and S_5 were chlorotic in appearance with premature abscission (needledrop) of the third year needles and poor leader growth while branches sampled at S_9 and S_{10} were comparatively darker green in color with a needle retention of from four to six years and good leader growth. The photosynthetic potential of lodgepole x jack pine trees based upon needle biomass alone therefore was much greater at S_9 and S_{10} compared to S_1, S_2, A_I or S_5.

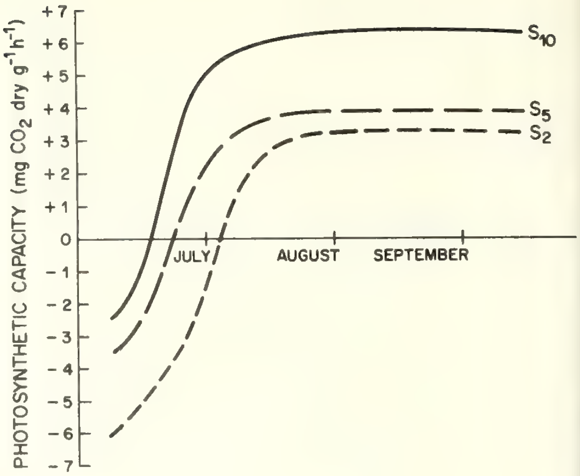

Figure 7. Comparison plot of the mean photosyn-thetic capacity of 1976 foliage on lodgepole x jack pine branches from sampling sites S_2, S_5 a S_{10} from early in June to mid-September.

When the observed ecological modifications c the forest ecosystem such as reduced needle bio mass, reduced biochemical energy, reduced photo synthetic rates, reduced soil pH, the disruptio of mineral nutrient cycling, foliar sulphur loa ing and the shortened growing season are combin and considered in the long term time sense the effect should be measurable as a reduction in forest productivity. This decrease in forest pr ductivity, however, would be expected to decrea with increasing distance from the sulphur gas emission source.

Annual basal area increment measurements we taken from 40 lodgepole x jack pine trees at ea of the five ecologically analogous sampling lo tions A_I through A_V in 1976 to determine if mo ification of the forest ecosystem was significa enough in the long term sense to be reflected reduced wood production since the initial star up of the West Whitecourt Gas Plant in 1961-19 Statistical analysis of the basal area increme data shown in Figure 8 revealed that distance the West Whitecourt Gas Plant, time in years, their interaction had significant effects on t basal area increment of the lodgepole x jack p trees from the five ecological analogues. An exponential growth curve model was determined lodgepole x jack pine trees from A_V and the gr curve of the lodgepole x jack pine trees from A_{II}, A_{III} and A_{IV} were statistically compared The basic underlying assumption was that sulph gas emissions had not had a significant effect the growth of the trees at A_V. This analysis statistically revealed that there has been a d nite reduction in basal area increment in lodg x jack pine trees since 1962 in A_I, A_{II}, A_{III} A_{IV} compared to the basal area increment model for A_V which was attributable to sulphur gas emissions from the West Whitecourt Gas Plant.

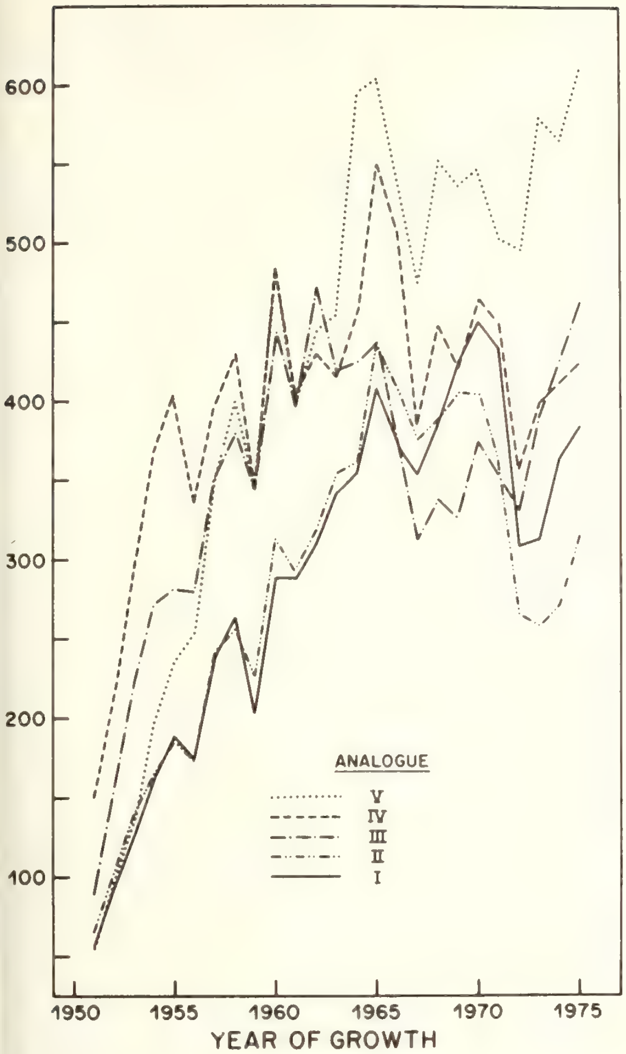

Figure 8. Comparative plots of the mean basal area increments from 40 lodgepole X jack pine trees at each of the five ecologically analagous sampling sites in the West Whitecourt study area.

maximum reduction in basal area increment urred at A_I and AII and progressively de- ased to zero at A_V. The effect of sulphur emissions on basal area increment growth lodgepole x jack pine trees since 1961 at A_{II}, A_{III}, and A_{IV} relative to A_V is thus radient with the reduction in basal area rement resulting from sulphur gas emission ling to zero at A_V or 9.6 km. If the total al area increment reduction of A_I relative A_V is averaged over the fourteen years since start-up of the West Whitecourt Gas Plant, s would correspond to approximately a one two percent reduction in basal area incre- t growth of A_I relative to A_V.

The areal extent of possible modification of ponents of the forest ecosystem by sulphur emission from the West Whitecourt Gas Plant be estimated using the following assumptions:

1. sulphur gas emissions reach the forest ecosystem within 17 km. (10.6 mi.) of the source; and
2. the impact of sulphur gas emissions is restricted to areas NW and SE of the West Whitecourt Gas Plant.

The area affected by sulphur dioxide emissions, therefore, is approximately 454 km^2 (175 mi^2) or 45,373 hectares (112,130 acres). This areal extent estimate of impact is conservative because the 17 km distance is only one-half the distance range calculated using the simple Gaussian plume model under all stability classes for maximum ground level concentration of sulphur dioxide emissions from the main incinerator stack.

It is important to bear in mind at this point, however, that this projected impact area has not been uniformly modified by sulphur gas emissions but rather has been modified in terms of an impact gradient extending NW and SE from the West Whitecourt Gas Plant. In other words, the extent of ecosystem component modification will decrease with distance from the sulphur gas emission source.

Another factor must be considered at this point. Sulphur emissions from the West Whitecourt Gas Plant have been reduced almost an order of magnitude since 1970 (refer to Figure 2). This significant reduction in emissions will not only generally decrease the magnitude of the impact of sulphur emissions on the forest ecosystem, it will also decrease the areal extent of the area impacted by sulphur emissions in the past thus allowing a portion of the forest ecosystem to recover from the previous sulphur gas emission stress.

When one uses foliar sulphate-sulphur concentration in lodgepole x jack pine trees as a measure of sulphur accumulation from exposure to the current level of sulphur gas emissions, it appears that a tolerable concentration is reached by 9-12 km (5.6-7.5 mi) of the West Whitecourt Gas Plant. This is indicated by a decrease in foliar sulphate-sulphur concentration with needle age which is within the range of the background foliar sulphate-sulphur concentration. The foliar $\delta^{34}S$ values, however, could be used to provide a more exact measure of the distance at which the presence of sulphur gas emissions become negligible to components of the forest ecosystem.

CONCLUSION

It is clear from this case study that sulphur gas emissions from the West Whitecourt Gas Plant have modified the forest ecosystem in a number of ways. The main ecological process which has been directly and indirectly affected by sulphur dioxide emissions is mineral nutrient cycling. By progressively altering the mineral nutrient balances of ecosystem components for example, the biological relationships amongst the components and the physiological and biochemical functions of the components are modified. It is these ecosystem

component modifications which are the expressions of environmental deterioration resulting from chronic exposure to sulphur dioxide over time. Despite this measurable deterioration of the forest ecosystem, however, it does not appear at this time that sulphur dioxide emissions from the West Whitecourt Gas Plant have caused irreversible ecological degradation. With the significant reduction in sulphur emissions from the West Whitecourt Gas Plant (See Figure 2) it is not anticipated that there will be significant irreversible ecological modification of the forest ecosystem in the remaining 10 to 20 years of operation of the West Whitecourt Gas Plant.

One philosophical dilemna has resulted from the West Whitecourt case study. There is no relationship between air quality standards and the maintenance of environmental quality since the term environmental quality excludes environmental modification. No effort to date has been made to address or to quantify acceptable limits of environmental modification resulting directly or indirectly from air pollution stress despite the fact that the presence of air pollutants in the atmosphere implies that a certain amount of environmental modification is acceptable.

Since, at the present time it is technologically and economically impossible to remove all air pollutants from industrial processes, it is suggested that irreversible ecological modification of the environment be used as an additional criteria for limiting pollutant emissions to the atmosphere. The assimilatory capacity of the environment, in other words, must be taken into account by both industry and regulatory agencies. The uniform application and enforcement of fixed air quality standards over a geographical area the size of the province of Alberta (661,183 km^2 or 255,285 mi^2) with its physiographically complex terrain, heterogeneous vegetation and diverse climatology is clearly not enough to maintain environmental quality. Future research will be required to determine the assimilatory and accumulatory capacity of the environment to pollutants and to provide the biological monitoring techniques to assure that the assimilatory and accumulatory capacity of the environment is not exceeded.

After the assimilatory and accumulatory capacity of the environment have been considered, flexible air quality standards may be possible. These standards could be adjusted regionally and seasonally in order to minimize pollutant impact on the environment. All emission sources, however, would have to be viewed in the context of their regional location, projected longevity of their operations, composition of their emissions, the proximity of neighboring emission sources as well as regional land use priorities since it is the total pollutant load to the environment which must be considered when one uses assimilatory capacity as a measure of environmental quality.

The conceptual interdisciplinary nature of the West Whitecourt case study has proven to be the basis for the success in unravelling the very complex interrelated consequences of the chronic exposure of the forest ecosystem to sulphur gas emissions from the West Whitecourt Gas Plant. It is suggested that future air pollution research on forest ecosystems follow a similar experimental design if the environmental perturbations caused by air pollution stress are to be understood. Direct extrapolation of the data summarized in this paper to other areas would be misleading unless local environmental factors, vegetation and pollutant parameters, are taken into consideration prior to interpretation.

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Effects of Airborne F on Forest Ecosystems[1]

Robert G. Amundson and Leonard H. Weinstein [2]

Abstract: Although there are many reports of fluoride (F) injury to forests, there have been no systematic studies on the forest ecosystem. In this paper, we have reviewed the present state of our knowledge on F pollution and effects on physiological processes, tree growth, F accumulation and plant injury, community structure, interaction with pathogens and insects, and distribution of F in the environment. The preparation of this review indicated the many areas of the F-plant interaction on which there is no information, where it is poorly understood, or where available information is highly controversial. In some cases, we have joined the controversy.

Injury to forest tree species by airborne .uoride (F) has been reported in many parts of ıe world (e.g., Adams and others, 1952; Horntvedt ıd Robak, 1975; Niklfeld,1975; EPA, 1973; Flühler ıd others, 1979), but many F-emitting sources are agricultural or urban areas and reports of jury to agronomic crops, ornamental and urban ees (e.g., Bolay and Bovay, 1965; Facteau and llenthin, 1976; de Ong, 1946; Leonard and Graves, 166) or on fluoride accumulation and production fluorosis in livestock and other herbivores (ıttie, 1977) are also common.

The principal industrial sources of airborne F are primary aluminum smelting; steel manufacture; conversion of fluorapatite to phosphate and phosphorus; and glass, ceramic and brick production. Natural sources of airborne F are principally from soil particles, fumaroles, and volcanoes. The ash from the recent eruption of Mount St. Helens contained 8 ppm soluble F (Stoiber and others, 1980) and 400 ppm total F and its impact on forests in the northwestern U.S. will be watched carefully.

Results of only a few field studies made near F-emitting sources are available in the scientific literature. One reason for the absence of more reports is that the studies were often routine and not quantitative, making publication in refereed journals difficult. A second reason is that results of a study performed for an industry may be sequestered from publication or other use because of active, pending, or potential litigation. Often, field studies that have been distributed were in a form that was not subjected to peer review, was carelessly assembled, and/or reflected the personal biases of the authors.

Because of these problems, we have not confined this review to works published in journals, but we have tried to judge the reports that we have cited in terms of their pertinence and/or availability, and our personal views are often presented. Most internal reports were avoided, but the lack of published information often left no recourse but to cite them. We hope that we have stated our criticisms of some studies as fairly as possible.

LABORATORY STUDIES ON PLANT PRODUCTIVITY

The productivity of the plant depends upon the coordination and rate of CO_2 assimilation, respiration, transpiration, translocation of photosynthate, mineral nutrition, growth, and reproduction. The amount of information available on

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the impact of airborne F on these processes ranges from virtually none, e.g., on translocation of photosynthates, to a moderate amount, e.g., on CO_2 assimilation (apparent photosynthesis) and respiration.

There are few data on the chemical composition, distribution, and patterns and frequency of exposure of atmospheric F in the field. One reason for this is that air monitors with short averaging times have not been generally available. Because F concentrations in the ambient air have not been characterized and fluctuating F concentrations are difficult to control, the design of meaningful laboratory or controlled field experiments is formidable. The information that is available is generally for averaging times of 12 or 24 hours (McCune and others, 1976) and the peak F concentrations that occur near sources are not known. This information would be very useful since it has been shown for other air pollutants, such as SO_2, that short-term peak exposures are more important in explaining plant damage than average concentrations (McLaughlin and others, 1979). Unfortunately, most laboratory studies have employed continuous exposures at constant concentrations that do not simulate field exposures. For these reasons the data available are of limited value in predicting the impact of airborne F on forest ecosystems.

Gas Exchange

Apparent Photosynthesis

Given the problems outlined above, it is not surprising that there have been so few studies on the effects of F on apparent photosynthesis (AP) of forest tree species (Table 1). Consequently, we have included in Table 1 not only studies on forest trees but also those on horticultural species exposed to hydrogen fluoride (HF) or supplied with sodium fluoride (NaF). We have arbitrarily separated experiments with HF into acute exposures (over 10 $\mu g\ m^{-3}$ for a few days or less) and chronic exposures (ca. 5 μg HF m^{-3} or less for a few days to more than a growing season), although we recognize that many exposures classified as chronic could more realistically be classified as acute. Exposures to solutions containing NaF have varied from several hours to months and will be discussed individually.

Acute exposures -- With the exception of cotton, where high concentrations of HF had no effect (Thomas, 1958), acute exposures have consistently reduced AP (Thomas and Hendricks, 1956; Thomas, 1958; Hill, 1969; Bennett and Hill, 1973). Bennett and Hill (1973) exposed alfalfa to HF for 2 hours and found that (1) approximately 120 $\mu g\ m^{-3}$ HF were needed to produce foliar necrosis; (2) about 40 $\mu g\ m^{-3}$ were necessary to clearly inhibit AP; (3) the depression of AP and subsequent recovery after exposure were slower for HF than for the other major air pollutants tested (SO_2, O_3, NO_2, NO and Cl_2). They also noted that of the pollutants tested, HF produced the greatest reduction in AP for an equivalent pollutant dose, but stat[ed] that the occurrence in the field of a concentration that would produce a 10 percent reduction i[n] AP would be rare. One can conclude that a significant influence of an acute exposure on plant community productivity would likely be preceded by lesions and abscission of foliage.

Chronic exposures -- Several investigators have reported that chronic exposure to HF had no effect on AP if there was no visible injury (Hill, 1969; Hill and others, 1958; Thompson and others, 1967), and when foliar injury occurred, the reduction in AP was proportional to (Hill, 1969; Thomas and Hendricks, 1956; Thomas, 1958) or greater than the amount of foliage injured (Thomas, 1958, for fruit trees; and Woltz and Leonard, 19[..], for citrus). Thomas (1958) proposed that there [is] a threshold of F concentration and duration of exposure for each species above which AP is reduce[d] more than can be accounted for by chlorosis and necrosis.

McCune and others (1976) described experiments in which field-grown sorghum was exposed for 14 days to three concentrations of HF (0.7, 1.7 and 3.5 to > 5 $\mu g\ m^{-3}$) and AP of the whole plant canopy was measured three times daily before, during, and after the exposure periods. The lowest HF concentration had no effect on AP; the intermediate concentration reduced AP during the exposure period, but immediate recovery occurred upo[n] cessation of the exposures. Plants subjected to the highest concentration also had reduced rates of AP for the first week. But when the HF concentration was raised to greater than 5 $\mu g\ m^{-3}$ on [the] eighth day, severe foliar injury occurred, the rates of AP dropped drastically, and there was [no] recovery in the post-exposure period.

In an extensive series of experiments, Kell[er] (1977) placed 11 different tree species (see Table 1) at varying distances from a source of [air]borne F for several months and measured rates o[f AP] on the whole plants returned to the laboratory. Exposure to F produced foliar injury and abscis[sion] and reduced the rate of AP of the whole plant. [The] reduction in AP of the whole plant was due prim[arily] to the loss of foliage, because the rate of AP [of] needles remaining on the plants was as high as [on] control plants.

Sodium fluoride -- Navara (1963) reported b[oth] depression and stimulation of AP of beans grown [in] solution culture for 16 days with 0.03 or 0.3 p[pm] NaF, while those supplied with 3 ppm had depres[sed] rates of AP. When Picea excelsa Link. cuttings [were] watered periodically through the winter and spr[ing] with deionized water containing 100 ppm NaF, th[e] AP rates were not only reduced but necrosis was produced on the newly flushed foliage. The F c[on]centrations in the new foliage that exhibited injury contained only 3.7 to 8 ppm when injury first occurred. By the end of July, those need[les] that survived contained from 31.5 to 52.2 ppm F (Keller, 1980).

McLaughlin and Barnes (1975) exposed cut anchlets of three pine species and leaves of six ciduous trees to 0, 1.9, 19, and 190 ppm NaF for hours and then measured the rates of AP. With 9 ppm NaF, the rates of AP of older needles of nus taeda L. and P. echinata Mill. were duced while the other species were unaffected e Table 1 for species used). Needles th reduced rates of AP contained less than 10 n F. Although low concentrations of foliar F duced AP and stimulated respiration, the authors rn of the limitations of extrapolating labora- ry data to the field situation. However, their a raised several questions: (1) What concen- ation of HF would be necessary to increase the liar F concentration 4-8 ppm in a 24-hour period did the comparable dose of NaF? (2) If upon osure to HF, a branch on a tree accumulated F the same rate, would the reduction in AP be manent or would it recover to the pre-exposure e after the exposure? (3) Would the 4-8 ppm rease in foliar F associated with the reduction AP produce visible injury? One could view this d of exposure as acute, because the comparable e of HF to accumulate this amount of F in 24 rs could be 4-8 $\mu g\ m^{-3}$, assuming an accumula- n coefficient of 1 ppm $\mu g^{-1}\ m^3\ day^{-1}$.

piration

Respiration (measured as oxygen uptake) was mulated in intact plants (Applegate and Adams, 0a; Applegate and others, 1960) or in tissues m intact plants fumigated with HF, in the ence (Weinstein, 1961; Applegate and Adams, 0b; Yu and Miller, 1967; Miller and Miller, 4) or presence of foliar lesions (Hill and ers, 1959). Fluoride inhibition of oxygen ake has also been reported and was dependent plant tissue age (Bejaoui and Pilet, 1975) ation of exposure (Applegate and Adams, 1960a), rient status (Applegate and Adams, 1960b), and sue F concentrations (Applegate and others, 0). However, the rate of respiration of some sues is relatively insensitive to F (Hill and ers, 1959; Givan and Torrey, 1968). In their eriments with cut branchlets of pines and hard- ds supplied with 1.9, 19 or 190 ppm NaF in ution for 24 hours, McLaughlin and Barnes (1975) nd that the lower two concentrations generally mulated respiration (measured as CO_2 evolution) le the highest concentration both stimulated inhibited respiration, depending on the cies.

nspiration and Water Use

There are few reports on the effects of F on nspiration. Navara (1963) grew beans in ution cultures containing 0.03, 0.3, and 3.0 F and found reduced rates of transpiration er 12 and 16 days in plants supplied with the highest concentrations of F. Soybeans fumi- ed with 12 $\mu g\ m^{-3}$ HF had dramatically reduced es of transpiration within 4 hours (Poovaiah Wiebe, 1973). This agrees with Navara and inda (1967) who found similar results in bean and apricot exposed to 70 $\mu g\ m^{-3}$ HF. But Thompson and others (1967) did not find significant differ- ences in water use of citrus exposed over a growing season to either ambient levels of F or filtered air with added F (both < 0.5 $\mu g\ m^{-3}$) compared to control plants. Amundson and others (in review) exposed corn to 1.5 $\mu g\ m^{-3}$ HF continuously for one week and found an increased rate of transpira- tion over controls. The data available on F effects on transpiration are variable and insuffi- cient to predict possible effects on plant commu- nity water relations. However, since F can elicit changes in stomatal aperture, these effects may be important in a forest ecosystem where water deficits limit AP at certain times of the day or year (Larcher, 1975; Kramer and Kozlowski. 1979).

Plant Metabolism

F has long been used as a metabolic inhibitor and the list of published reports of F effects on enzyme systems and metabolic processes is extensive. Many of the effects of F on plant metabolism have been reviewed (McCune and Weinstein, 1971; Chang, 1975) and Horsman and Wellburn (1976) have com- piled a useful list of F-induced metabolic re- sponses.

Since F alters normal plant metabolism, efforts have been made to identify metabolites that could be used as indicators of incipient F injury. Yee-Meiler (1975) found that non-specific esterase activity in young Norway spruce (Picea abies [L.] Karst.) and European white birch (Betula verrucosa Ehrh.) exposed to airborne F was increased late in the growing season without the appearance of injury symptoms. Needles of conifers placed at varying distances from an in- dustrial F source had significant increases in phenols if they came from trees with F injury (Yee-Meiler, 1977). The results were variable for deciduous trees. Keller and Schwager (1971) found increased peroxidase activity in leaves of seven tree species exposed to an industrial source of HF and noted that the enzyme activity increased before or in the absence of development of F injury symptoms. Unfortunately, many environmental stresses and laboratory manipulations can increase peroxidase activity, limiting the usefulness of this assay (Endress and others, 1980).

Mineral Nutrition

Wide differences in the response of peaches to HF led to the first study of the influence of mineral nutrition on HF susceptibility (Brennan and others, 1950). With low or deficient amounts of N, Ca, and P in tomato foliage, there was re- duced uptake of NaF by roots or HF by leaves; similar results were found with excessive amounts of N and Ca (Brennan and others, 1950). Other studies have resulted in increased foliar F in P-, K-, or Fe-deficient beans (Applegate and Adams, 1960c); reduced foliar F in Mg-deficient tomato plants (MacLean and others, 1969); smaller fruits in Ca-deficient tomato plants (Pack, 1966); and increased tolerance to HF exposure in tomato plants

Table 1. Reported effects of fluoride (HF and NaF) on apparent photosynthesis (as measured by changes in CO_2 uptake) of higher plants.

Genus or Species	Concentration µg m^{-3} HF	Duration	Response	Reference
Gladiolus	0.8 - 8.0	7 days	pct. reduction in AP = pct. injury	Thomas & Hendricks 56
Hordeum	32	4-8 hours	total interruption in AP with	
Medicago	200	4-8 hours	recovery in few hours to days	
Fruit trees	16-40	4-8 hours		
Hordeum	32	2 hours	AP reduced during exposure with	Bennett &
Medicago	32	2 hours	recovery after exposure	Hill 73
Lycopersicon	1.4 - 5.2	4 weeks	no effect	Hill &
	0.9 -11.2	3 weeks	no effect	others 59
Fruit trees	2.1 av.	183 hours	14 pct. reduction in AP 10 pct. injury	Thomas 58
Gladiolus	3.1 - 5.2	30-205 days	pct. reduction in AP = pct. leaf injury	
Gossypium	13.6	138 hours	no effect	
Citrus	.32 -.77	growing season	no effect	Thompson others 67
Gladiolus	0.8	39 days	no effect	Hill 69
	1.2	27 days	3 pct. reduction over injury	
Fragaria	2.3	63 days	no effect	
	38	1 day	50 pct. reduction	
Lycopersicon	5.1/12	17/21 days	no effect	
Prunus	1.6	42 days	no effect	
Zea	7.7	16 days	no effect	
Sorghum	0.7	14 days	no effect	McCune &
	2.2 then 1.7	12/2 days	reduced with recovery after exposure	others 76
	3.5 then 5+	7/7 days	reduced during 3.5 exposure then severely injured little recovery	
Pinus sylvestris *P. nigra* *P. strobus* *Larix leptolepis* *Quercus borealis* *Pseudotsuga menziesii* *Picea excelsa* *Alnus incana* *Sorbus Aria* *Acer pseudoplatanus* *Larix decidua*	ambient near source	Nov- April	reduced AP of whole plant due to loss of foliage with visible injury on remaining foliage	Keller 77
Cornus florida *Liquidambar Styraciflua* *Plantanus occidentalis*	1.9 ppm NaF	24 hours	AP reduced in older needles of *P. taeda* and *P. echinata*	McLaughlin others 75
Acer rubrum *Liriodendron tulipifera* *Oxydendrum arboreum*	19 ppm NaF	24 hours	AP reduced in all species	
Pinus strobus *P. taeda* *P. echinata*	190 ppm	24 hours	AP reduced in all species	
Picea excelsa	100 ppm	winter- spring	AP reduced in old foliage/new injured	Keller 80

rown with excess Mg (MacLean and others, 1976).

There is little information on the effects of on forest tree nutrition, but there is a considerable amount of information on mineral cycling n forest ecosystems (Grier and Cole, 1972; Bormann nd Likens, 1979), and airborne F can influence his cycling in forest vegetation (see "Tree rowth").

Growth and Production

Effects of F on the physiology and metabolism f plants are ultimately manifested as changes in he height, diameter, dry weight, and reproduction f the plant. But most of the available literaure describes studies with agronomic crops.

Relatively low concentrations of F have been eported to stimulate growth, but growth can be nhibited by amounts of foliar F that do not prouce chlorosis or necrosis in the same species Treshow and Harner, 1968).

The effects of F on reproduction have been emonstrated and its possible implications disussed by Pack and Sulzbach (1976). They hypothsized that lowered seed production was a result inhibition of pollen germination or pollen tube rowth, inhibiting or preventing fertilization. rowth of pollen tubes in apricot (Facteau and we, 1977) and sweet cherry (Facteau and others, 73) was reduced by HF fumigation during flowerg, but Dinh and others (1973) found no effect on eet cherry pollen tube growth after exposure to µg F m^{-3}.

Joint Action with Other Pollutants

Experiments on the joint action of HF with her pollutants have emphasized effects on F cumulation (Matsushima and Brewer, 1972; Mandl d others, 1975, 1980), foliar lesions (Solberg d Adams, 1956; Hitchcock and others, 1962; ndl and others, 1975, 1980); and growth and eld (Matsushima and Brewer, 1972; Mandl and hers, 1980). Field studies that attempt to termine the response of plants or plant communites to F emissions must consider not only environntal and edaphic factors (Treshow and others, 67), but also the presence of other pollutants unce, 1978; McClenahen, 1978; Carlson, 1978) at complicate assessment of the impact of F one. McCune (1980) has discussed published and published results of experiments with HF in mbination with SO_2, O_3, and NO_2.

FIELD STUDIES

F has many characteristics that make it an al toxicant to study in an ecosystem. Firstly, is an apparently non-essential element that mally occurs in foliar tissues at a concentran of <10 ppm; thus, the presence and amount of borne contamination can be measured. Secondly, s easily identified with specific emission sources. Thirdly, the source strength is often known and can be applied to dispersion modelling. Fourthly, F is not very mobile in plants and tends to accumulate along the margins and distal end of the leaf. Consequently, most of the F that enters a leaf remains, except for that lost by weathering and perhaps a small amount by translocation. But, as mentioned earlier, one major drawback is the difficulty of monitoring ambient concentrations.

Smith (1974) recognized three broad classes of air pollutant-dose relationships with respect to potential impacts on forest ecosystems. The Class I relationship pertains to a very low dose where the forest acts as a sink for the pollutant and the impact may be unmeasurable or stimulatory. A moderate dose relationship (Class II) is expected to cause significant direct and indirect physiological impairment to individuals resulting in reduced growth, reproduction and/or increased morbidity. With a high dose (Class III), there is acute morbidity resulting in ecosystem simplification with drastic changes in primary productivity, mineral cycling, succession, etc.

All three pollutant-dose relationships have been described in one form or another around F sources (Bunce, 1978; Treshow and others, 1967; Carlson and Dewey, 1971; Wheeler, 1972).

Fluoride Accumulation in Soils

The amount of total F in soils that has been reported ranges up to 8300 ppm but is generally from 20-500 ppm (Weinstein, 1979). In general, plants are poor accumulators of soil F (Hansen, 1958; MacIntire and others, 1949; Merriman and Hobbs, 1962; McClenahen, 1976), but there are some exceptions, notably species of Theaceae, such as tea and camellia (Zimmerman and others, 1957; Zimmerman and Hitchcock, 1956), hickories and flowering dogwood (McClenahen, 1976).

The deposition of fluoride in soils near sources of emission has been the subject of several investigations. McClenahen (1976) examined the geographic distribution of total F in soils at two seasons and at different distances from an alumina reduction smelter. Of course, the highest accumulations occurred in the direction of the prevailing winds and extended about 10 km. In areas where F deposition was lowest, total F increased with depth of the soil profile, but the opposite was true in areas where deposition was heaviest. There was a lower concentration of F in the soil profile in outlying areas than near the source. The total F in the soil profile in low and high impact areas over the two-year study period was consistently different. No attempt was made to correlate soil F with the amount of F accumulated by plants.

Relatively large amounts of F-containing amendments are necessary to increase the accumulation of F in plants (Weinstein, 1977), and Israel (1974) has estimated that each 120 µg/g increment

in soil F resulted in a gain in forage F of 1 µg/g.

The accumulation of F in conifer needles and in "soil-humus" samples near a phosphorus plant in Canada has been studied (Thompson and others, 1979; Sidhu, 1977). Severity of damage to vegetation was reported to be correlated with F concentration of foliage and of "soil-humus". Because the distribution of airborne F in soils would be expected to follow the same pattern as in vegetation, it would be difficult to estimate the proportion of F present in foliage that was accumulated from the atmosphere and that from the soil. Water-soluble F from the "soil-humus" was positively correlated with foliar F and because the soils were highly acidic, root uptake could have been an important pathway into the vegetation.

The soil as a source of F to plants has not been adequately investigated and the long-term effect of acidic precipitation in making soil F available to plants, especially in acidic, non-agricultural soils should be investigated. There are many other gaps in our understanding of the cycling of F in forest ecosystems, such as the effects of F accumulation on litter decomposition, on changes in nutrient availability, and on soil structure.

F Accumulation and Occurrence of Injury

In many reports, the authors have presented values for the F content of vegetation at different distances (and sometimes, directions) from a source, but often they did not provide information on the source strength, ambient air concentration, or the forms of airborne F that were present. Often, qualitative or semi-quantitative estimates of injury are given and there is little or no consideration to other possible causes of injury, such as insects, pathogens, environmental stresses, or even the presence of other pollutants. These data are most useful in evaluating the relative sensitivity of different species, the interspecific differences in sensitivity, the most sensitive stages of plant or foliar development, the components of the forest ecosystem most vulnerable to an effect, and, if evaluated carefully, the dose of atmospheric F or the amount of tissue F accumulated to produce a measurable effect, whether it is registered as a metabolic or physiologic change or as a chlorotic or necrotic lesion.

As one would expect, the atmospheric concentration of F and the amount accumulated in vegetation decreases with distance from the source (Treshow and others, 1967; Sidhu, 1977, 1978; Thompson and others, 1979; Roberts and others, 1979; Bunce, 1978, 1979; Wheeler, 1972; Carlson and Dewey, 1971). The amount of F accumulated in foliage, however, will depend upon many factors including the dose and form of F, the species, accessibility of the pollutant to the plant (e.g., screening of understory by overstory species), plant-to-plant variability, etc. In general, broadleaf species will accumulate more F than conifers when they occur together (Sidhu, 1977, 1978); and great differences can occur between conifer species, ceterus parabus, with the most tolerant ones accumulating the most F (Weinstein 1977). A likely explanation for this is that wh the most sensitive species are injured (metaboli cally or physiologically) by a given dose of F, continued absorption and accumulation are reduce

Not only are the most tolerant species the mo efficient accumulators, but the amount of accumu tion and the threshold for injury within a genus (or even species) may be vastly different in different forest ecosystems. For example, Tresh and others (1967) did not find needle injury in Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franc in Idaho at F concentrations in needles that averaged 150 ppm (composite value for the curren year, 2-year-old, and 3-year-old needles), while Carlson and others (1979) reported that "mottlin or chlorosis was present at 6-8 ppm" (needles of uncertain age). Obviously, this difference is reflected in part by the environmental differenc between the study areas (Idaho and Montana) but other differences between the results of the two studies should be considered. Firstly, Carlson and others (1979) analyzed a number of needle characteristics at different distances from the source of fluoride emissions in Montana. The mo common needle injury observed was mottling (presumably chlorotic mottling) and, although signifi cant it was a weak association that did not corr late very closely with F content of needles. Th R^2 values for F content of needles and needle mottle in Douglas-fir, lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) and white pine (*Pinus monticola* Lamb.) were 0.0266, 0.0445, and 0.1604, respectively (Carlson, 1980). But one might conclude from the original report that the occurrence of mottling on these conifer needles was increased greatly by F. The possibility tha other pollutants associated with this symptom, s as ozone or another oxidant, would be distribute in the same air mass as F was not considered. Carlson and others (1979) also concluded that th is no threshold content of F in needles above which injury will occur, and that any detectabl amount of atmospheric F is detrimental to conif This is a simplistic explanation and it ignores several facts. The first is that all conifer needles are not equally sensitive to F injury, is noted in many compilations (e.g., Weinstein, 1977; Fluorides, 1971; Thomas and Alther, 1966) Secondly, sensitivity to F is related to the ag of the needle at the time of exposure. It woul be absurd to assert that "adverse effects were visible on needles when their fluoride concentra reached 8-10 ppm" (Carlson and others, 1979) of F accumulated after the conifer needles had completed their elongation. Thirdly, the form of to which needles are exposed and whether it is internal or superficial would also determine th kind of effect produced. Finally, if there is threshold for injury then there are no mechanis of detoxification in plants and physiologic or metabolic processes, such as photosynthesis or enzyme activity, that have been altered by F sh evidence no recovery. There is ample proof tha once a fumigation ceases, or if the periods betw

ccessive fumigations are sufficiently separated, covery processes (repair mechanisms) are active ee Dinman, 1972; McCune and Weinstein, 1971; omas and Alther, 1966). Carlson and others 979) appear to have equated injury from F with ch destructive agents as ionizing radiation.

Another interesting contrast in the sensitivity conifers to F is exemplified by the conditions ar a phosphorus plant at Long Harbour, Newfound- d and an alumina reduction smelter at Kitimat, . The Long Harbour area is classified as onging to the Boreal Forest. Its productive ests are 8-12 m tall and are composed princi- ly of dense stands of balsam fir (Abies samea [L.] Mill.) and black spruce (Picea iana [Mill.] B.S.P.). Non-productive scrub ests are less than 5 m tall and are composed larch (Larix laricina [DuRoi] K. Koch), black uce, and balsam fir. Rock-barrens and peat- ds are common (Thompson and others, 1979). ls are generally shallow, precipitation is vy, and the forests are exposed to high winds taining saline aerosols.

Kitimat is in the Pacific Coastal Rain Forest a. The forest is an uneven-aged, overmature, adent, and stable climax forest. Logging is important commercial activity. The forest sists of about 60% western hemlock (Tsuga erophylla [Raf.] Sarg.), 25% balsam fir (Abies bilis [Dougl.] Forb.), 7% western red cedar uja plicata Lamb.), 6% yellow cedar (Chamaecy- is nootkatensis [Lamb.] Spach.), and 2% sitka uce (Picea sitchensis [Bong.] Carr.). The rage age of fir and hemlock is more than 300 rs, and it is not unusual to observe trees of 2 m dbh. Total annual precipitation is about inches and occurs on 53% of the days. The lies in a wide trough that runs north and h, and bisects the Coast Mountains (Reid, ins, 1976).

missions at the Long Harbour phosphorus plant not known, but are certainly lower than those itimat, which have ranged from 2.5 to 6.6 tons aseous F/day between 1955 and 1977 (Alcan eillance Committee, 1979). F concentrations onifers were frequently higher than 100 ppm ate summer without evidence of any foliar ons. This can be contrasted to the published shold value for needle injury in balsam fir ong Harbour of as low as 14 ppm (Sidhu, 1978). ough the same species do not occur in the two s, the different responses of conifers are so king that one must conclude that (1) it is possible to generalize from one site to another, foliar F contents alone may be a poor deter- nt of injury, and (3) environmental stresses h as wind, salt, nutrient, or water) are as rtant predictors of an effect as is F content.

t is difficult to classify conifers and other species into groups based upon their relative rance to airborne F because most compilations based upon foliar injury, and not according ffects on timber volume, fruit production, or other objective criteria related to the intended use of the tree.

There is insufficient information to develop these kinds of lists because existing compilations are based primarily on field and laboratory observations of foliar injury. Sensitivity lists based on foliar injury (Weinstein 1977, 1979) are only a guide and do not provide evidence of relative effects on plant processes.

Tree Growth

Many studies have identified F as the cause of tree mortality around industrial sources (Adams and others, 1952; Scurfield, 1960; Jung, 1968; Robak, 1969). The determination of F as the causal agent usually entailed determination of foliar F concentrations and, occasionally, air quality monitoring. In these class III relationships (Smith, 1974), determination of the area of impact is normally easy to identify. This is not true for class II relationships for several reasons: (1) environmental factors (mainly weather patterns) change from year to year and not only distribute the pollutants randomly but also produce more or less favorable growing conditions for the impacted vegetation; (2) normal biotic factors (insects and pathogens) and abiotic factors (soils) also account for variability in growth; (3) stage of development of the stands of trees also dictate growth rates and the degree of competition between individuals; and (4) all of these factors combined with pollutant exposure produce a given effect. Therefore, to quantify the reduction in growth caused solely by the pollutant, the variability due to the other parameters must be accounted for.

Treshow and others (1967a) measured radial growth,needle length, needle dry weight, and foliar fluoride concentrations in Douglas-fir (Pseudotsuga menziesii [Mirb.] Franco) located at different distances from a fluoride source (also see "F Accumulation and Occurrence of Injury"). They classified the study plots into three groups based on foliar F concentrations of composite samples of four age-classes of needles. The groups were control (average 24 ppm F), intermediate fluoride (average 150 ppm F), and high fluoride (average 225 ppm and with some needle necrosis). Significant reductions in radial growth were found in both groups subjected to elevated F concentration. There was a significant negative correlation of needle length with radial growth, but there were no significant effects on needle dry weights. Thus, they found that (1) radial growth reduction can occur without foliar lesions and (2) Douglas-fir needles can average as much as 150 ppm F without foliar injury.

A study of the impact of F on nutrient cycling in stands of loblolly (Pinus taeda L.) and slash pines (Pinus elliotti Engelm.) and the impact on tree growth was made by Wheeler (1972). No injury symptoms attributable to F exposure were noted in the sample plots but trees at the edge of some stands did show some "burning of needles".

Increased foliar F concentrations (from 13 to 49 ppm in pooled samples) were correlated with increased return rates of Ca and K from greater leaf leaching and of Ca, K, and Mg by greater litterfall. This altered nutrient cycling presumably should alter productivity but no relationship was found between needle concentrations of F, Ca, Mg, and K and productivity as measured by amount of bole wood. Wheeler (1972) concluded that either these fluctuations in needle status did not affect growth or that the sampling was insufficient to detect differences that were present.

Extensive studies on growth and F accumulation have been made at Kitimat, B.C. (Bunce, 1978) and Columbia Falls, MT (Carlson, 1978). Both areas were subjected to F for many years before any scientific assessment of growth reduction due to F were made and each area was subjected to insect infestation (see section "Insects").

Bunce (1978) used "foliage analysis, observations of lichens, air flow patterns and topographic features" to estimate the area of impact and to establish the distribution of his sample plots. Tree ring cores were taken from western hemlock, the dominant species, from all sample locations, and were used to determine the amount of growth reduction due to F emissions. After variability in growth rates due to weather, insect infestation, and another pollutant (SO_2) were accounted for, Bunce (1978) reported the annual loss of wood production to be 950 cunits (95,000 cu. ft.) per year compared to the 800,000 cunits attributed to insect damage. Obviously the cause of the insect outbreak is fundamental to the assessment of the magnitude of the F-related effects on growth and is discussed elsewhere. Although the primary and secondary (bark beetles) insect outbreaks ended by 1968, F emissions have continued at a lower rate since 1975 and trees in the insect damaged zone are regenerating satisfactorily. The question of whether there is a cause-and-effect relationship between F emissions and insect infestation has not yet been answered for reasons discussed elsewhere.

F from an aluminum reduction plant in Columbia Falls, MT caused growth reductions in Douglas-fir fir, lodgepole pine, and western pine (Carlson, 1978, 1979). However due to questionable assumptions and miscalculations, an overestimate of the loss of usable timber due to F pollution was made. Statistically, the data (Carlson, 1978) showed only a weak correlation between foliar F concentrations and reduced radial growth. The area of growth reduction was substantially smaller than reported previously (Carlson, 1980). It has also been stated (Carlson, 1978) that any increase in foliar F above background concentrations is detrimental to tree growth. This assumption was generated by the implied growth reduction of trees located in areas designated as having reduced growth; but upon closer examination of the data, no growth reduction could be demonstrated (Carlson, 1980). Consequently, the original assumption, which implies that there is no thr hold concentration of foliar F below which inj does not occur, cannot be substantiated. This is not meant to imply that F is not phytotoxic because it is the most toxic of the common atm pheric pollutants. But an understanding of it effects in the ecosystem, requires much resear and the synthesis of an enormous amount of information. Koch's Postulates were not writt frivolously.

Community Structure

Large areas of the Eastern United States ar subjected to a complex mixture of air polluta from urban centers and industrial sources. Mo of the Eastern Deciduous Forests are subjecte to at least moderate air pollution (Class II). McClenahen (1978) studied the effects of a mi ture of pollutants derived from industrial so (containing F, SO_2, NOx, chloride, and oxi on changes in structure and composition of a deciduous forest in the Ohio River Valley. T study sites were arbitrarily divided into ove story, subcanopy, shrub and herb layers and t stands were measured for diversity (Pielou, 1 evenness (Williams, 1977), and species compos

In general, the average total stand densiti of the overstory and herb layers were found t decrease in proximity to the F source while t subcanopy and shrub layer increased with the layer being the only layer that showed a signi correlation to F exposures. Chloride from an source had a greater influence in the other l

Murray (1979) conducted a study of plant c ity structure around an aluminum smelter in Australia. Although a number of study sites lost by fire, he was able to ordinate species associations with F stress. More of these ki of studies are needed to provide data to pred the risk of an effect when an ecosystem is ex to airborne F.

Incidence and Severity of Diseases and Insect

There is evidence, from laboratory and fie experiments or observations, that airborne F alter the plant-pathogen and plant-insect rel tionships. The exact relationships between F these biotic stresses and their underlying me anisms are only beginning to be understood.

Plant pathogens -- Although there are many dustrial sources of F, we are not aware of an field or laboratory reports that link airborn with incidence or severity of forest tree dis It is necessary, therefore, to discuss some l tory research on the effects of HF on disease crop plants in order to evaluate possible for effects and to establish research needs.

The plant-pollutant-pathogen interaction w reviewed by Heagle in 1973 and Laurence in 19 For the kinds of effects that have been found McCune and others (1973) provided three possi

lanations: (1) there could be a direct effect the pollutant on growth and development of the anism; (2) the pollutant could affect the susceptibility of the plant to the pathogen; and (3) pollutant could affect the microbiota or microironment of plant surfaces and thereby affect pathogen.

Tobacco leaves infected with tobacco mosaic us and containing 200-300 ppm F had a higher er of virus than control leaves when a local ion assay was used. The titer was lower at 500 F (Dean and Treshow, 1966; Treshow and others, 7b). But perhaps the best evidence for a ct effect of airborne F on growth and develop-: of a pathogen was the consistent reduction ean powdery mildew (Erysiphe polygoni DC.) d as a result of HF fumigation, indicating HF was affecting the infectivity of the patho- itself, because reduction in disease was pro-ional to the length of the exposure period, ction was continuous throughout the exposure od, and the pathogen itself is epiphytic.

he most likely mechanism for an effect of F on t pathogenic diseases would be an alteration he susceptibility of the host plant to the ogen. The reduction in the numbers of bean (Uromyces phaseoli [Pers.] Wint.) uredia by and post-inoculation exposures to HF may have due to a change in host metabolism by the mulation of F (McCune and others, 1973). The evidence available that suggests an indirect ct of F was found in halo-blight of bean udomonas phaseolicolus [Burkh.] Dows.) where collapse was affected, but foliar symptoms not. Thus, the site affected was spatially ved from the site of F accumulation, the leaf ne and others, 1973).

ere is no reason to believe that crop plants d respond differently than forest species to rne F and plant pathogens, and laboratory and studies are needed to determine and evaluate ts on the incidence of disease and possible miological consequences.

sects -- The controversies associated with ffects of F on plants in general, and eco-ms in particular, also extend to the possibil-hat F alters the relationship between plants estructive insects, that F kills beneficial ts, or that accumulation of F in insects makes a vehicle for the transfer of F in ecosystems. is ample evidence that an association can between F-contaminated vegetation and insects, he relationship is not understood and it does ccur under all conditions or with all insects.

effer (1962-1963) reported that attack by beetles, snout beetles, and fir leaf rollers associated with F emissions in a fir forest echoslovakia. Carlson and Dewey (1971) and on and others (1974) have reported that F ulation in conifer foliage is closely related festations by several destructive insects: needle scale (Phenacapsia pinifoliae Fitch), pine needle sheath miner (Zellaria haimbachi Busck), needle miner (Ocnerostyma strobivorum [Zeller]), and sugar pine tortrix (Choristoneura lambertiana [Busck]) that ranged from no significance (larch casebearer) to a non-significant trend (pine needle scale) to strong evidence of a weak correlation (needle miners). Only about 6% of the variation in needle damage by needle miners was associated with foliar F concentration. There was an even more remote association between needle miner population and foliar F concentration. Edmunds and Allen (1956) and Compton and others (1961) found no association between pine needle scale (Nuculopsis californica [Coleman]) and the extent of F injury or F content of needles of ponderosa pine (Pinus ponderosa Laws) and Edmunds (1973) questioned the results of Carlson and Dewey (1971). Thalenhorst (1974) and Wentzel (1965) found positive relationships between spruce galls induced by Adelges abietes (L.) and F. But Temple (personal communication) could find no correlation between the F content of washed silver maple foliage and galls induced by the bladder-gall mite (Vasates quadripes [deShimer]).

One of the most interesting examples of a possible F-plant-insect association was observed near an alumina reduction smelter in Kitimat, B.C. (see section on "F Accumulation in Plants and Occurrence of Injury" and "Tree Growth"). Between 1960 and 1963, an epizootic of saddleback loopers (Ectropis crepuscularia [Denis & Schiff.]) and spruce budworms (Choristoneura orae Free.) occurred that killed many trees over a large area that coincided well with the pattern of fume dispersion. In 1961, balsam bark beetles (Pseudohylesinus grandis [Swaine] and P. nebulosus [Lec.]) appeared as secondary pests throughout the area attacked by the looper and the budworm. We used the word "possible" above in referring to F as the causal agent in this outbreak because (1) there is no way now to establish a cause-and-effect relationship; (2) the emissions were also high in particulate materials, sulfur compounds, pitch volatiles, and even CO_2; (3) the problem was not studied at the time that the outbreaks occurred; and (4) other possible etiologies have been suggested by entomologists from the Canadian Forestry Service. Several of the theories that might explain the insect attacks at Kitimat are: (1) F absorbed by the foliage of the tree alters its metabolism and increases its attractiveness to insects; (2) F weakens the tree, rendering it less able to resist insect attack; (3) gaseous or particular emissions are toxic to parasitic and/or predaceous insects that provide important controls of the population of destructive insects; (4) the emissions have a "blanket" effect that results in a slight temperature alteration and gives the larvae of the loopers and budworm a competitive advantage over parasites and predators; (5) loopers and budworm moths were carried on winds into the Kitimat area and dispersed in the same pattern as smelter emissions; and (6) there were an unusually large number of lights in the valley above the smelter in the early 1960's and they provided light of wavelengths that attracted moths (Alcan Surveillance Committee,

1979).

Although the primary and secondary insect attacks were extremely destructive, amounting to a total net loss of mature timber estimated at 800,000 cunits (80,000,000 cu. ft.) (Reid, Collins, 1976) a considerable number of trees were not damaged and regrowth has been extensive. In some areas near the smelter, F-induced injury was a prominent feature on young hemlock, Sitka spruce, black cottonwood, and even western red cedar (Weinstein, unpublished field reports for 1971 and 1974 cited in Alcan Surveillance Committee, 1979). In the intervening years, especially since 1975, there has been a substantial reduction in total emissions from the smelter (more than 50% between 1975 and 1977), accompanied by greatly reduced foliar injury. Nevertheless, vegetation exhibiting no foliar symptoms often contains 100 ppm F or more, and the incidence of insect attack is no greater than in nearby areas not exposed to the smelter emissions. Because any reduction in emissions would include gaseous F, particles, and other components of the fumes, no cause- and effect-relationship can be made. From subjective observations, however, particulate emissions have been reduced strikingly, at least since 1971, and we feel that this fraction of the emissions was perhaps of great significance in the original outbreaks. Certainly, the indirect relationship between an increase in insect colonization and particles has been known for many years (Bartlett, 1951). Even before Carlson and his colleagues were attempting to demonstrate a relationship between F and insects on U.S. Forest Service land and in Glacier National Park, an enormous outbreak of mountain pine bark beetle (Dendroctonus ponderosae [Hopkins]) was beginning on the Canadian border many km to the north. It extended throughout the entire Flathead National Forest and the western part of Glacier National Park, and has destroyed many thousands of lodgepole, ponderosa, and white pines.

Although there is little doubt that an association exists between airborne contaminants and insect outbreaks, the evidence for a cause-and-effect relationship with F in unconvincing, and at times it appears that some investigators have forced a relationship. Insect outbreaks occur in unpolluted as well as polluted areas. The question to be resolved is not whether there is or isn't a relationship between airborne substances and insects, but to determine the nature of this relationship and the features it has in common with other stresses.

Evaluation of F Injury in the Field

The most common measures of F injury to forests include (1) assessment of the presence and amount of foliar injury, especially of indicator species; (2) loss or depletion of sensitive receptors and community changes; (3) measurement of biomass production; and (4) the accumulation of F in plant tissues that might produce foliar injury or render the plant unsuitable for indigenous herbivores.

Regardless of the approaches used, the path to useful information can be a difficult and confusin one, as is well-known for other atmospheric pollutants. Some of these problems have been discussed by Weinstein and McCune (1970).

There are a number of indigenous plant specie that are sensitive to atmospheric F, including goa weed (Hypericum perforatum L.), common barberry (Berberis vulgaris L.), Oregon grape (Mahonia repe [Lindl.] Don. and M. nervosa [Pursh.] Nutt.), blue berry (Vaccinium spp.), and young needles of many conifers (see Table 2 for a list of F-sensitive higher plants). One general conclusion can be mad field observations of plants can be a good qualitative but is usually a poor quantitative indicator of effects.

In many cases of F pollution, there has been severe depletion of lichen populations (reviewed by Gilbert, 1973). In areas nearest the F source, a lichen desert may exist, but they appear and increase in frequency and diversity with increasing distance from the source (LeBlanc and others, 197 Nash (1971) and LeBlanc and others (1971) transplanted several species of lichens into the field in areas of F-emitting industries and found that the species used were injured near the source (but sometimes up to 10 km away) and were effective F accumulators. Corticolous lichens accumulate F more rapidly than saxicolous species, and consequently, demonstrate accelerated damage and reduced abundance (Perkins and others, 1980), but much research remains to characterize and classify the sensitivity of the different lichen types growing on their many kinds of habitats.

Problems associated with the measurement of biomass have been discussed in many treatises on forest mensuration, and Bunce (1978, 1979) and Parker and others (1974) have discussed the probl associated with discriminating between effects of insects, and environmental stresses in evaluating effects on tree growth. The relationship between F accumulation and production of foliar lesions o other effects, is discussed elsewhere, and fluoros in indigenous herbivores is beyond the scope of this review.

F Distribution in the Environment

In its most elementary form, the transfer of F to and from the atmosphere, waters, soils and rocks, and living organisms, due to natural or an pogenic causes, has been described (Fluoride, 197 Weinstein, 1977). F that is accumulated in plant enters the food chain through herbivores and pass into the soil in their wastes. The transfer from one animal to another is possible in the case of insects that have accumulated F on or in their bodies and are eaten by birds or other carnivores but this has not been studied. It is also not kn if increased levels of F associated with a variet of insects was due to accumulation by ingestion o by surface contamination. Hughes and others (in preparation) cultured cabbage loopers (Trichoplus ni [Hubner]) on two kinds of diets. One containe

ncreasing amounts of F as NaF or KF and equivalent amounts of control cabbage. The other contained F from HF-fumigated leaves and was combined with control leaves to give the same dose urve. Analyses of prepupae and pupae showed hat F accumulated in the bodies of the loopers upplied with F salt (ca. 10 pct. of the concentration of the diet on a dry weight basis); no accumulated in loopers grown with the fumigated abbage diet. There was evidence that loopers rown with the latter diet developed faster and rew larger than those on the control cabbage aF or KF diets. These results suggest that the reported as having accumulated in insects probably was due to surface contamination of particles Carlson and Dewey, 1971; Dewey, 1973). Ingestion of surface-contaminated insects by carnivores, owever, still transfers the F to the next trophic vel, but the amount of accumulation that might cur at that level is not known.

There are great differences in the capacities plants growing in the same soils to accumulate Most plants accumulate low concentrations of (0 - 10 ppm), but some species can accumulate undreds of ppm from the same soil. In any species, soluble F in the soil solution can be readily absorbed by plants (Romney and others, 1959). When deposited upon plant surfaces, the relatively insoluble forms of F have low phytotoxicity (McCune and others, 1977), but their ingestion can be harmful to herbivores. Consequently, the main source of phytotoxic airborne F is HF.

Once it enters a leaf, F moves in the transpiration stream to the tips or margins of the leaf and stays in a form that can be leached from many leaves (Leone and others, 1956; Ledbetter and others, 1960; Jacobson and others, 1966). Consequently, foliar concentrations of F need not steadily increase (Knabe, 1970). Twigs of deciduous species can accumulate F in the winter, presumably through the lenticels, and elevated concentrations have been found in young foliage in the spring (Keller, 1974, 1978). A small proportion of F entering a leaf can also be translocated to other parts of the plant (Kronberger and others, 1978).

already present in most soils is in an insoluble form and has little influence on vegetation. The fate of F leached from foliage and of F deposited directly from the atmosphere has not been studied extensively. Any effect will depend upon the nature and chemistry of the soil. Flühler and others (1979) have shown that leaching of particulate F depends upon its water solubility (NaF > powdered pine needles containing F > cryolite > CaF_2). The F in powdered pine needle litter leached nearly as rapidly as did NaF. When NaF solutions were applied to soil columns, organic matter, aluminum, and iron were lost, but the amount depended upon the soil type.

Effects of F on soil composition and structure, mineral cycling, and litter decomposition are important aspects of the impact of F on forest ecosystems and research in these areas should have a high priority.

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Air Pollution—a 20th Century Allogenic Influence on Forest Ecosystems[1]

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Abstract: Chronic doses of ozone, sulfur dioxide, nitrogen oxides, hydrogen fluoride and other primary or secondary gaseous air contaminants may cause subtle effects on forest ecosystems. Air pollutants may influence reproduction, nutrient cycling, photosynthesis, predisposition to entomological or pathological stress or quantity of healthy foliar tissue. Forest ecosystem response to chronic air pollution may include alterations in growth rates and successional patterns. The establishment of comprehensive field and laboratory investigations to systematically examine chronic air pollution stress on forest ecosystems in those parts of the world subject to atmospheric contamination is concluded to be of top priority. In the United States, forest ecosystems judged to be at particular risk and in need of more intensive investigation include the Northern Hardwood forest, Central Hardwood forest and Western Montane forest.

The interactions between air contaminants [an]d forest ecosystems are extremely complex, [b]ut can be conveniently divided into three [maj]or classes (Smith 1980). Under conditions [o]f low dose - Class I relationship - the [veg]etation and soils of forest ecosystems [f]unction as important sources and sinks for air [p]ollutants. When exposed to intermediate dose [- Cl]ass II relationship - individual tree [sp]ecies or individual members of a given [sp]ecies may be subtly and adversely affected by [n]utrient stress, impaired metabolism, [pr]edisposition to entomological or pathological [st]ress, or direct disease induction. Exposure to high dose - Class III relationship - may induce acute morbidity or mortality of specific trees. At the ecosystem level the impact of these various interactions would be very variable. In the Class I relationship, pollutants would be exchanged between the atmospheric compartment, available nutrient compartment, other soil compartments and various elements of the biota. Depending on the nature of the pollutant, the ecosystem impact of this transfer could be undetectable (innocuous effect) or stimulatory (fertilizing effect). If the effect of air pollution dose on some component of the biota is inimical then a Class II relationship is established. The ecosystem impact in this case could include reduced productivity or biomass, alterations in species composition or community structure, increased insect outbreaks or microbial disease epidemics and increased morbidity. Under conditions of high dose and Class III relationship, ecosystem impacts may include gross simplification, impaired energy flow and biogeochemical cycling, changes in hydrology and erosion, climate alteration and major impacts

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on associated ecosystems.

This paper is specifically concerned with Class II interactions resulting from forest ecosystem exposure to chronic doses of ozone, sulfur dioxide, nitrogen oxides, hydrogen fluoride or other primary or secondary gaseous air contaminants. It specifically addresses the relationship between these gases, and their mixtures, on forest reproduction, forest metabolism and direct forest stress as detailed by previous contributors to this section and attempts to examine resulting perturbations in ecosystem structure and function.

FOREST REPRODUCTION

Sexual reproduction of forest trees is critically important for maintenance of genetic flexibility and the persistence of most species in natural forest communities. Reproductive strategies, however, are typically beset by a variety of "weak points" and reproductive growth of many forest trees is, at best, irregular and quite unpredictable. Generally there is a very good correlation between tree vigor and the capacity for flowering and fruiting (Kramer and Kozlowski 1979). A variety of environmental constraints impose restrictions on tree reproductive processes. Because air contaminants may reduce tree vigor and in view of the fact that numerous potential points of interaction have been identified between air pollutants and reproductive elements (Smith 1980), it has been hypothesized that air contaminants may impact forest ecosystems by influencing reproductive processes.

Considerable evidence has been presented indicating a potential adverse impact of numerous gaseous pollutants on pollen metabolism. Other papers have indicated reduced cone and fruit production under field conditions (Smith 1980). If one or more of these various reproductive stress mechanisms is operative in natural forest ecosystems, it is possible that changes in species composition may ultimately occur. In their study of ozone impact on the understory vegetation of an aspen ecosystem, Harward and Treshow (1975) concluded that only one or two years of ozone exposure might be sufficient to cause shifts in community composition because of seed production responses to ozone exposure.

FOREST METABOLISM

Photosynthesis is the most fundamental metabolic process of forest ecosystems and is the primary determinant of growth and biomass accumulation. The rate of net photosynthesis of mature trees frequently is within the range of 10-200 mg of carbon dioxide taken up per gram of dry weight per day. The rate is extremely variable, however, and influenced by genetic, clonal and provenance differences, season of the year, time of day, position within the crown of the tree, age of foliage, climate and edaphic factors.

Studies with a wide variety of agricultural and herbaceous species, under controlled environmental conditions, have indicated that air contaminants must be added to the list of environmental variables that can potentially alter the rate of photosynthesis.

Because of ease of handling and experimental design, investigators studying the relationship between air pollutants and tree photosynthesis have primarily employed tree seedlings for research material and controlled environmental facilities for growth. Evidence has been provided, under the above circumstances, for photosynthetic suppression caused by sulfur dioxide, ozone, fluoride, heavy metals and coal dust. The thresholds of photosynthetic toxicity for tree seedlings vary with individual species and individual pollutants. For several seedlings the threshold of sulfur dioxide photosynthetic influence may approximate 1 ppm (2620 $\mu g\ m^{-3}$) or less for an exposure of several hours. For ozone, the threshold of photosynthetic response may approximate 0.5 ppm (980 g m^{-3}) or less for an exposure of several days (Smith 1980).

Considerable risk is associated with extrapolation of seedling photosynthetic data accumulated in controlled environmental facilities to older trees in natural forests. Excised leaf and small chamber techniques, therefore, have been employed to assess the air pollutant influence on photosynthetic rates of trees five-years-old and older. The use of sapling-age experimental material avoids the unique characteristics of seedling metabolism. Evidence for forest tree sapling photosynthetic suppression has been presented for sulfur dioxide, ozone and cadmium. For sulfur dioxide and ozone exposure, the sapling evidence suggests that the threshold of photosynthetic reduction may approximate 0.5 to one ppm for 5-10 hours for one or two days (Smith 1980).

Much of the seedling and sapling evidence suggests that the photosynthetic inhibition caused by sulfur dioxide and ozone is reversible if the pollutant stress is removed. Under the circumstance of variable pollutant concentration in ambient atmospheres, photosynthetic recovery might be common. Synergism, or greater stress resulting from simultaneous pollutant exposure relative to either pollutant alone, appears frequently in the seedling and sapling literature. Evidence for synergistic photosynthetic suppression by sulfur dioxide and ozone and fluoride and cadmium has been presented. Almost all of the studies report photosynthetic depression in the absence, or at least prior to, the appearance of visible

›liar symptoms.

The evidence for air pollution induced ıotosynthetic suppression in large trees in ıtural environments is extremely meager and agile. The seedling - sapling evidence ›wever, demonstrates a threshold of effect ıat approaches ambient concentrations in merous temperate environments. Because of e profound importance of the photosynthetic ocess and the potential for suppression by despread air contaminants, appropriate field udies must be conducted in spite of their fficulty and cost. The opportunity to amine the impact of contaminants on spiration and transpiration should also be cluded in experimental designs. Inclusion of e or both of these physiologic processes in edling - sapling studies has revealed some dication for significant alteration. creased respiration coupled with reduced otosynthesis could exacerbate growth nsequences.

FOREST FOLIAGE

Under conditions of sufficient dose, air lutants directly cause visible injury to est trees. The accumulation of particulate taminants on leaf surfaces or the continued ake of gaseous pollutants through leaf mata will eventually result in cell and sue damage that will be manifest in foliar ptoms obvious to the trained, but unaided . This direct induction of disease in trees air pollutants is the most dramatic and ious individual tree response of all Class I interactions. It is the only Class II eraction that can be detected in the field casual observation. Unlike altered oductive strategy, nutrient cycling, tree abolism or insect and disease relationships; h degree of foliar symptoms induced by air lutants can be relatively easily observed, ntoried and quantified. In the presence of ficient dose, tree damage may be of icient severity to cause mortality.

Acute foliar disease may be caused in est vegetation by widespread air aminants including; sulfur dioxide, ogen oxides, ozone, peroxyacetyl-nitrates, ride and several trace metals, and lized air contaminants including acid rain, nia, chlorine, hydrocarbons and hydrogen ide. The response of woody plants to these spheric pollutants is extremely variable dramatically controlled by genetic factors, t age and health and environmental itions. Field symptoms of air pollution y are not highly specific, are mimicked by le variety of other tree stress factors and useful only to experienced observers liliar with the range of edaphic, nological and pathological stress factors acteristic of a given flora in a given location. The dose required to produce acute injury varies widely with pollutant and vegetative type. There has been sufficient work done to enable a generalized ranking of relative forest tree sensitivity to the most important air pollutants (Davis and Wilhour 1976). A summary treatment of general symptoms and injury thresholds for the gaseous contaminants included in this section is contained in Smith (1980).

FOREST ECOSYSTEM RESPONSE

The primary response of a forest ecosystem to sustained intermediate dose and Class II interaction would be reduced growth and consequently reduced biomass. Reduced essential element availability, decreased photosynthesis, increased respiration, increased insect and disease stress and decreased foliar tissue would all contribute to a reduction in tree growth rates and ultimately to lessened forest biomass. Alterations in the reproductive strategies of individual tree species or differential response of these species to reduced nutrition, altered metabolism and pest stress and to direct foliar injury may cause changes in competitive ability and ultimately lead to alterations in tree succession and species composition. Recent reviews of Class II vegetative responses to air pollutants include Heck and others (1977), Jensen and others (1976) and Weinstein and McCune (1979).

Forest Growth

Forest growth is complex in concept and measurement. Addition of woody tissue is the dominant feature of forest growth. The accumulation of woody biomass (living weight) represents gross photosynthetic production less respiratory losses. The most fundamental characteristic of an ecosystem is its productivity. Forest productivity is high relative to other ecosystems and net productivity of 1200 dry g m^{-2} $year^{-1}$ for trees and shrubs together is quite typical for temperate forests (Whittaker 1975). Productivity is strongly controlled, however, by a variety of variables including system age and environmental parameters. The most important of the latter include nutrient availability, water availability and temperature. Because of the variety of Class II interactions identified, air quality also influences forest productivity in certain environments.

Productive forests are critically important, not only for the obvious relationship between wood volume and commercial products in managed forests, but also for the regulation and maintenance of quality for associated ecosystems, amenity functions and general climatic and terrestrial stability. It is disconcerting to realize, therefore, that

there is substantial and impressive evidence to indicate that two widespread air contaminants, sulfur dioxide and ozone, are capable of reducing forest growth. The more localized release of fluoride can also reduce the amount of forest biomass (Smith 1980).

Evidence from a variety of studies examining forest growth in the vicinity of large point sources of sulfur dioxide has indicated significantly reduced growth. Generally the correlation of growth impact with degree of foliar injury caused by sulfur dioxide is not high. Growth retardation occurs in the absence of any visible indication of stress. Most sulfur dioxide studies have accounted for precipitation influence on forest growth over the study periods. Evidence for ozone suppression of forest growth has been provided by the comprehensive oxidant impact study of the Western Montane forest ecosystem in California. Localized reduction of forest growth may also occur in environments subject to elevated levels of fluoride.

There are two serious deficiencies of forest growth - air pollution stress research. The first relates to the paucity of ambient air quality determinations in growth studies. This makes establishment of dose thresholds or correlations of dose with growth influence nearly impossible. The second serious limitation relates to the inability to partition reduced growth to the various Class II interactions that may actually be responsible for it. For example, what percentage of reduced growth may be due to reduced nutrition, reduced photosynthesis, increased insect or disease activity or increased foliar damage?

Future investigations of forest growth, as impacted by air quality, must also include better accounts of growth influencing factors other than precipitation and air pollutants. Better awareness of additional climatic factors, impacts of insect and disease influence, and management strategies must be indicated.

Forest Succession

As a result of the considerable varietal and species variation in relative susceptibility to the various Class II interactions, it is reasonable to suppose that differential tolerance to air pollution influence at the species level may be reflected in altered patterns of succession and species composition at the ecosystem level.

Ecologists recognize two major types of processes that influence ecosystem succession. Autogenic processes are those resulting from biological factors within the system. In forest ecosystems autogenic processes would include site alterations caused by the vegetation, influence of one plant species on another and impact of native insect or disease microorganisms. Allogenic processes, on the other hand, are abiotic factors that influence succession from without the system. Geochemical and climatic forces are especially important examples of allogenic factors that influence forest ecosystems. Idealized ecosystem development characteristically is portrayed as an orderly change of biological progression occurring in a more or less constant environment (Odum 1969, Woodwell 1974). It has been generally assumed that autogenic processes dominate allogenic processes in terrestrial ecosystem succession. This generalization, however, is quite inconsistent with data generated by recent imaginative studies with forest ecosystems. The importance of fire (an allogenic force) in influencing pre-settlement forest ecosystems in the North Central states of the United States has been substantial (Loucks 1970, Frissell 1973, Heinselman 1973). The significance of wind stress (an allogenic force) has been suggested to exert substantial control over successional development of forest ecosystems in New England (Stephens 1955, 1956, Raup 1957, Henry and Swan 1974). Forest management practices imposed by man, for example clear-cutting, may simulate the influence of natural allogenic forces on forest development and interrupt progress toward a steady state condition (Bormann and Likens 1979). Conversely other forest management procedures, for example fire control, may eliminate a controlling allogenic force and permit succession to proceed toward an unnatural steady state condition. Class II stresses imposed on forest ecosystems by air pollutants may be considered a 20th Century allogenic process of potential importance to forest ecosystem development. As in the case of clearcutting, this human related force might be expected to alter the attainment of steady state conditions. Air pollution stress would appear to have certain unique qualities that may make it an allogenic influence of particular importance. Length of exposure to this force precludes evolutionary adjustment and its influence, in certain areas, may be quite continuous rather than cyclic as are windstorms and fires. What is the evidence available to support the importance of air pollution as an allogenic force of significance in forest ecosystem development?

In 1968, prior to sophisticated understanding of most Class II interactions, Treshow (1968) provided an excellent review of the impact of air contaminants on plant populations. Treshow's review, along with a variety of additional late 1960's papers, for example Niklfeld (1967), Hajdúk and Ružička (1968) and Trautmann and others (1970), have indicated alterations in successional patterns or species composition in forest ecosystems subject to air pollution exposure.

The forests of the San Bernardino

ountains in southern California have been ıbject to oxidant stress from the Los Angeles etropolitan complex for thirty years. ıtensive investigations conducted in the San ernardino National Forest over the years have ovided valuable insight and perspective on a ıriety of forest air pollution relationships. ı 1970, Cobb and Stark concluded that if air llution from the Los Angeles basin continued increase, there will be a conversion from ell stocked forests dominated by ponderosa ne (Pinus ponderosa Doug ex. Laws) to poorly ocked stands of less susceptible tree species the San Bernardino Mountains. Miller (1973) ıs provided a thorough discussion of this idant induced forest community change. nderosa pine is one of five major species of e "mixed conifer type" that covers wide areas the western Sierra Nevada and the mountain nges, including the San Bernardino Mountains, southern California from 1000 to 2000 m 000-6000 feet) elevation. Other species presented include sugar pine (Pinus mbertiana Dougl.), white fir (Abies concolor ord. & Glend.] Lindl.), incense-cedar ibocedrus decurrens Torr.) and California ack oak (Quercus kelloggii Newb.). The sponse of these five major tree species to idant air contaminants in the San Bernardino tional Forest has been variable. Ponderosa ne exhibits the most severe foliar response elevated ambient ozone. A 1969 aerial survey nducted by the U.S.D.A. Forest Service dicated 1.3 million ponderosa (or Jeffrey, nus jeffreyi Grev. & Balf.) pines on more an 405 km^2 (100,000 acres) were stressed to me degree. Mortality of ponderosa pine has en extensive. Actual death is typically tributed to bark beetle infestation of air llution stressed trees. White fir has ffered slight damage, but scattered trees ve exhibited severe symptoms. Sugar pine, cense cedar and black oak have exhibited only ight foliar damage from oxidant exposure. A 2 ha (575 acre) study block was delineated in e northwest section of the San Bernardino tional Forest in order to conduct an tensive inventory of vegetation present in rious size classes and to evaluate the althfulness of the forest. Ponderosa pines the 30 cm (12 inch) diameter class or larger re more numerous than any other species of mparable size in the study area. These pines re most abundant on the more exposed ridge est sites of the sample area. Mortality of nderosa pine ranged from 8-10 percent during 8-1972. The loss of a dominant species in a est ecosystem clearly exerts profound change that system. Miller concluded from his estigation that the lower two-thirds of the dy area will probably shift to a greater portion of white fir. It was judged that ense cedar will probably remain secondary to te fir. Sugar pine was presumed to be tricted by lesser competitive ability and arf mistletoe infection. The rate of position change was deemed dependent on the rate of ponderosa pine mortality. The upper one-third of the study area, characterized as more environmentally severe due to climatic and edaphic stress, supports less vigorous white fir growth. Following loss of ponderosa pine in this area, sugar pine and incense cedar may assume greater importance. Miller judged, however, that natural regeneration of the latter species may be restricted in the more barren, dry sites characteristic of the upper ridge area. California black oak and shrub species may become more abundant in these disturbed areas. Additional and intensive research on forest composition in the San Bernardino National Forest has been reported (Miller 1977). Tree population dynamics were examined on 18 permanent plots established in 1972 and 1973 and on 83 temporary plots established in 1974 to investigate forest development as a function of time since the most recent fire. Generally the data still support the hypothesis that forest succession toward more tolerant species such as white fir and incense cedar occurs in the absence of fire. In the presence of fire, pine may be favored by seedbed preparation and elimination of competing species. These more recent studies suggest a larger number of forest subtypes may exist within the forest ecosystem than initially realized.

The changes in forest composition caused by oxidants in this southern California forest have created a management concern, as well as ecological change, because the forest is intensively used as a recreational resource and the loss of ponderosa pine is judged to reduce aesthetic qualities of the forest.

Other examples, not as dramatic as the San Bernardino example, can be found. Hayes and Skelly (1977) have monitored total oxidants and associated oxidant injury to eastern white pine in three rural Virginia sites between April 1975 and March 1976. Varieties of pine categorized as sensitive and intermediate to oxidant stress were judged to be under stress. The authors speculated that susceptible eastern white pine (Pinus strobus L.) in the Blue Ridge and Southern Appalachian Mountains may be rendered less competitive by air pollution stress. Shifts in species composition away from white pine importance along with other changes in tree distributions may be occurring in certain eastern regions. Brandt and Rhoades (1973) in their investigation of limestone dust impact in deciduous forests in southwestern Virginia predicted changes in species composition resulting from dust influence. Dusty sites had reduced seedling and sapling density of red maple (Acer rubrum L.), chestnut oak (Quercus prinus L.) and red oak (Quercus borealis Michx. f.). This observation along with documentation of reduced mean basal area and lateral growth of these trees, led the authors to suggest that yellow-poplar (Liriodendron tulipifera L.), more resistant to

stress caused by dust accumulation, would increase in importance in these hardwood stands.

Treshow and Stewart (1973) have conducted one of the few studies truly concerned with air pollution impact on an entire vegetative community. Portable fumigation chambers were placed over representative plants in intermountain grassland, oak, aspen and conifer communities. Ozone fumigations were conducted to establish injury thresholds for 70 common plant species indigenous to these communities. Generally injury was evident at varying concentrations above 15 pphm (294 $\mu g\ m^{-3}$). Species that were found to be most sensitive to ozone in the grassland and aspen communities investigated included some dominants which were considered key to community integrity. The most dramatic example was aspen (Populus tremuloides Michx.) itself. Single two-hour exposure to 15 pphm ozone caused severe symptoms on 30 percent of the foliage exposed. White fir seedlings require aspen shade for optimal juvenile growth. The authors judged that significant aspen loss might restrict white fir development and alter forest succession. In a companion study, Harward and Treshow (1975) pursued their interest in evaluating ozone impact on aspen communities by evaluating the growth and reproductive response of 14 understory species to ozone. Plants were fumigated in greenhouse chambers throughout their growing seasons. It was concluded from these fumigations that plant sensitivities varied sufficiently to make probable major shifts in composition in aspen communities following only a year or two of exposure to ozone above concentrations of 7-15 pphm (137 - 294 $\mu g\ m^{-3}$). The authors observed that comparable doses are widespread in the vicinity of urban areas and that widespread impacts on plant community stabilities may be common in nature. The efforts of Michael Treshow and colleagues highlights the importance of examining shrub and herb strata when assessing air pollution impact on forest ecosystems.

McClenahen (1978) has provided a most interesting study with quantitative data on the impact of polluted air on the various strata of a forest ecosystem. Forest vegetation was measured in seven stands on similar sites in a 50 km area of the upper Ohio River Valley. The stands were situated along a gradient of polluted air containing elevated concentrations of chloride, sulfur dioxide, fluoride and perhaps other contaminants. Species richness (number of different species) evenness (dominance index - low values indicate dominance by one or a few species) and Shannon diversity index were typically reduced within the overstory, subcanopy and herb strata near industrial sources of air contaminants. Increasing air pollutant exposure reduced canopy stem density, but abundance of vegetation in other strata tended to increase along the same gradient. The relative importance of sugar maple (Acer saccharum Marsh.) was greatly reduced in all strata with increasing pollutant dose, while yellow buckeye (Aesculus octandra Marsh.) appeared tolerant of poor air quality. In the shrub layer the importance of spicebush (Lindera benzoin [L.] Bl.) increased with increasing pollutant exposure.

In southern California the predominant native shrubland vegetation consists of chaparral and coastal sage scrub. The former occupies upper elevations of the coastal mountains, extending into the North Coast ranges, east to central Arizona, and south to Baja California; while the former occupies lower elevations on the coastal and interior sides of the coast ranges from San Francisco to Baja California. Westman (1979) applied standard plant ordination techniques to these shrub communities to examine the influence of air pollution. The reduced cover of native species of coastal sage scrub documented on some sites was statistically indicated to be caused by elevated atmospheric oxidants. Sites of high ambient oxidants were also characterized by declining species richness.

Influence of air pollution stress on succession and ecosystem species composition probably varies with the age and successional status of the forest. Harkov and Brennan (1979) have observed that most woody plants susceptible to ozone injury are generally early successional plant species. Most trees intermediate or tolerant of ozone stress are typically mid- or late successional types. It is not unreasonable to propose, as Harkov and Brennan did, that late successional forest communities may be the most resistant to compositional change as a result of chronic air pollution exposure. Mature ecosystems are also typified by other characteristics that may increase their resistance to air pollution stress. Low net production may reduce potential importance of restrictions imposed by air contaminants on photosynthesis. Closed and slow nutrient cycling may make nutrient capital less liable to loss by air pollutant influence.

There is increasing appreciation of the importance of allogenic forces on forest ecosystem succession. The significance of fire and wind stress on forest development is substantial in certain environments. It is concluded that air pollutant impact may also exert critically important control over forest succession and species composition. Long-term, continual stress tends to decrease the total foliar cover of vegetation, decrease the species richness, and to increase the concentration of dominance by favoring a few, tolerant species.

CONCLUSIONS

Large areas of the temperate forest osystem are currently experiencing major rturbation from air pollution. The influence a variety of air contaminants on ogeochemical cycling, patterns of succession d competition and individual tree health, signated Class II interactions (Smith 1980), e causing significant forest change in the mperate zone. At the ecosystem level the .jor perturbations include decreased oductivity, biomass and diversity; at the mmunity level reduced growth; and at the pulation level altered species composition. rly and mid-successional forests are ncluded to be at particular risk. Temperate :ests have historically been subjected to jor change resulting from the activities of man beings. For centuries the major fluence was gross destruction for ricultural, fuel or other wood-product rposes. In the present Century reduced need agricultural land and increased forest nagement has reduced the adverse impact on :ests in temperate latitudes. Human ivities of primary contemporary importance forest structure and function have included introduction of exotic arthropod and crobial tree pests into forest systems :king evolutionary exposure to these tructive agents, enhancement of native and ural stresses by cultural practices, and the ation of artificial forests of one or a few mercially important species. In the past eral decades, however, we have accumulated ficient evidence to indicate that an itional major anthropogenic modifier of perate forest ecosystem development is air lution.

Research

During the last decade forest researchers e outlined numerous Class II interactions by gely utilizing relatively young forest nts grown in controlled environment ilities. During the next decade we must e an effort to perform experiments in ural forest ecosystems to confirm our otheses that ambient air pollution is ucing forest productivity and altering cies composition.

The very highest research priority is erved for the establishment of comprehensive stigations to systematically examine Class I nteractions in forest ecosystems located in se portions of the temperate zone :icularly subject to air pollution stress. e investigations should include analysis of contaminant influence on soil metabolism structure, nutrient cycling, tree oduction, photosynthesis and respiration, rtant arthropod and microbial pathogens, ar symptoms of important vegetation in all forest strata and a careful examination of forest productivity and alterations in successional trends and species dominance. These studies will be of extended term. They will require the participation of numerous scientific disciplines, minimally including pathology, entomology, meteorology, soil science, soil microbiology, ecology and systems analysis. Continuous meteorological and air quality monitoring will be required. Air pollutants measured should include sulfur dioxide, nitrogen oxides, hydrocarbons, ozone and particulates, the latter to include determination of sulfates, nitrates and trace metals. Precipitation acidity will be routinely determined. The objective of these comprehensive studies will be to clarify and quantify various Class I and II interactions. The ecosystems will be evaluated for their ability to resist (inertia) and respond (resilience) to disturbance from air pollution stress. Model development for the various interactions will hopefully allow future projections, given various air quality scenerios, and allow extrapolation of findings to other ecosystems.

In the United States the only research program presently addressing this need is the oxidant study in progress on the San Bernardino National Forest in California. It is imperative that additional investigations be initiated as soon as possible. The studies should be established in those areas judged to be under the greatest stress and they should be initiated, where possible, in association with integrated and comprehensive forest ecosystem studies currently in progress. Priority forest ecosystems in the United States include: 1) Northern Hardwood forest, 2) Central Hardwood forest and 3) Western Montane forest (San Bernardino project in progress). Appropriate locations, in terms of existing research facilities or abundant ancillary information, for the Northern forest are the Hubbard Brook Experimental Forest in New Hampshire, the Isle Royale National Park, Michigan and the Itasca Forest, Minnesota. In the Central forest the Camp Branch Forest watershed in east-central Tennessee and the Coweeta Hydrologic Laboratory in western North Carolina would be appropriate. With regard to location, the Wayne National Forest in Ohio would appear to represent an interesting research opportunity. In addition to the San Bernardino Forest study, the Andrews Experimental Forest, Oregon and the Bitterroot National Forest, Idaho would be other strategically located sites for the Western Montane forest.

Policy

It is recognized that air pollution is one of the most significant contemporary anthropogenic stresses imposed on temperate forest ecosystems. Gradual and subtle change in forest metabolism and composition over wide

areas of the temperate zone over extended time, rather than dramatic destruction of forests in the immediate vicinity of point sources over short periods, must be recognized as the primary consequence of air pollution stress. This realization means that forest interactions with air contaminants must be given consideration in deliberations concerning clean air laws and regulations, alternative energy strategies, industrial and transportation location and forest research funding.

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Secondary and Interactive Effects of Chronic Gaseous Pollutant Exposure of Producers, Consumers, and Decomposers

Influence of Chronic Air Pollution on Mineral Cycling in Forests[1]

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Abstract: This paper reviews the literature concerning the impact of chronic air pollution on mineral element cycling in forests. The concept involves the forest trees taking up essential and other elements from the soil and surrounding environment eventually to return them to the soil upon mortality and decay. Chronic pollutants are considered in the context of this cycling as another form of elemental addition to the site subject to cycling in the same manner. The review is organized to assess the addition of the major elements, carbon, nitrogen, and sulfur, and the trace metallic elements. In addition, pollutant effects upon the ecosystem living components in terms of producers and decomposers are considered along with potential changes in the redox and pH state of the different portions of the forest. Some original data on foliar composition of Big Cone Spruce (Pseudotsuga macrocarpa (Vasey) Mayr) in relation to pollution exposure, and the evaluation of a soil subject to increments of hydrogen in simulated acid rain leaching are presented.

INTRODUCTION

This paper will present a review of various aspects of mineral element cycling in forests as affected by chronic atmospheric pollution.

The forest will be considered to the stand of trees and that portion the atmosphere encompassed by canopy a trunk space, and the portion of the so encompassed by the root space. Miner cycling is the process of cycling of el- ments from the soil through uptake roots or by foliage, transport within t trees and the eventual return to t forest soil in the processes of foli leaching, root exudation, foliage dro, etc. Return to the soil storage occur, and the cycle is continued by upta again, or it may be broken by loss fr the soil, or tieup as insoluble precip- tates or compounds. Air pollution exp sure will be considered to be the add- tional atmospheric inputs which enter t nutritional and elemental cycle forests due to man made effects on atmo pheric composition.

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ELEMENTAL CYCLING

The idea of the cycling of elements rom vegetation to soil, following uptake rom soil probably outdates written ecords as is apparent from the primitive gricltural practice of shifting cultivaion wherein a forest is cut and burned or soil enrichment by the ash. This is ollowed by the regrowth of a fallow orest crop, which in turn is burned gain. The forest vegetation cycles elents essential for vegetative growth as ll as unncessary elements accidental to e particular environment. The 16 or 17 sential elements (C, H, O, P, K, N, S, ., Fe, Mg, Mn, Cu, Zn, Mo, B, Cl, and rhaps Se), are cycled by necessity for thout them there would be no forest. addition almost every other element is anslocated by plants. This concept is ed in geochemical prospecting for many the more valuable elements, using the ant as a chemical prospector (NASA 68). These elements which are cycled y be enriched in concentration in varis portions of the cycle, as in the liage, the plant detritus on the ound, or in the surface of the soil neath the plants. Such enrichment is ten the indication of an extraneous ement. Similarly the input of extranes elements in the process of pollution y be evidenced by enrichment over the rmal background amounts.

The state of the vegetation and its pacity for storage of elements will ermine the relative change induced by addition of a pollutant element. The te of the vegetation is partly deterned by the fact that vegetation is a nt reduction reaction in which phoynthesis reduces carbon from carbon xide to carbon in reduced carbon comnds as described by Stumm and Morgan 70). The forest trees carry out this uction reaction, followed by their th and the subsequent oxidation of the bon compounds in the soil. The ling of the elements on the site curs in the context of this giant redox ction (Garrels, et al., 1975), and its te and magnitude determine the rate amount at which the other elements l be cycled.

The cycling of most of the elements ch undergo redox changes in the forest rient cycle (C H O N S Mn Fe) will d to be reduced in the living etated portion of the cycle and comte the cycle to an oxidized form in soil. However, local soil factors oring anaerobic conditions such as r in excess, may cause the soil to me a sink for some elements in the uced form, or for other elements in oxidized form.

Thus pollutants may enter the elemental cycles in forests and vary in mobility depending upon the redox potential at various portions of the elemental cycle. Some pollutants may also be oxidants in relation to the portion of the ecosystem that is absorbing them and thus affect the redox potential at that point according to Haagen-Smit (1958).

STORAGE POINTS AND SINKS

The soil and vegetation of the forest have several points of long term storage of materials added to the elemental cycling system. It has been learned from past fertilization experience that elements added to the forest, either to soil or direct to trees, may be stored for varying periods of time in different portions of the forest. Obviously, the tree trunks provide storage of the materials contained in the wood for the length of life of the tree and its subsequent decomposition time. Deciduous portions of the tree retain materials for lengths of time proportionate to their residence time on the tree; bark for longer periods, leaves and twigs for lesser periods. The storage time in the decomposing or oxidizing portions of the detritus dropped to the soil depends upon local environmental conditions of temperature, redox state, and availability or toxicity of elements to decomposing (oxidizing) organisms. For example, decomposition times for surface detritus on the soil surface in a forest may vary from a fraction of a year to many years.

The soil beneath the forest is a giant fixed-bed ion exchanger, and once elements enter the soil following release from storage in the vegetative portion of the forest and its detritus they may be stored on this exchange complex. The capacity of this ion exchange bed as well as the nature of associated cations will determine the storage probability of elements added to the forest whether as additives (pollutants, fertilizers), or in the normal course of mineral weathering or rainfall additions. The total capacity of this bed for cation exchange in coniferous forest soils ranges from 40 to 300 gm equivalents per meter squared to a meter depth (Zinke, et al., 1979). Whether the pollutant added has a significant effect depends upon the natural base line composition of other cations on the soil column (usually H^+, Ca^{++}, Mg^{++}, K^+, Na^+) maintained. by the forest and the lyotropic series (leaching precedence) of these elements. The forest soil also has anion exchange capacity although usually of lesser amount. Thus, depending upon the nature of the pollu-

tant additive, and whether it attains ionic form, it may be subject to scrubbing out at the soil exchange complex stage of the elemental cycle. This would apply to the hydrogen and sulfate of acid rain, or the cationic forms of some metallic pollutants such as lead or zinc. Laboratory simulation through leaching with successive increments of the pollutant such as acid rain can be made readily to determine this capacity, and an example of this follows later.

The soil has other capacities for storage of additives in addition to that of the ion exchange capacities. Either following breakthrough or saturation of the exchange capacity, an additive element may be stored on the metallic oxide complex of the soil, or as insoluble precipitates or oxides. The release and uptake of elements into storage in association with the metallic oxides (usually iron and manganese) will depend upon the pH and redox potential of the soil as reviewed by Jenne (1968). Retention will be least under the reducing conditions brought about by large amounts of organic matter and poorly drained - wet conditions.

Thus, the forest soil is a major determinant in the fate of the chronic pollutant element added to the forest. The break through capacity of the soil for the added material will depend upon the current input of similar elements by the natural cycling of cations from the tree cover, the inputs by current mineral weathering, the current additions of hydrogen from rainfall and organic compounds produced by the forest, the depletion of basic metallic cations taken up by the tree growth as the trees age on the site. The greater the storage capacity of the soil either as ion exchange or metallic oxide (hydrous) capacity the greater the buffering capacity of the forest on the input of pollutants.

It will be of interest now to review some of the experience of how the various pollutants behave in relation to these processes of elemental cycles in a forest.

POLLUTANT ADDITIVES TO FOREST CYCLES

Any of the elements added to the forest as pollutants can influence elemental cycling, either by acting as nutrient elements required for the growth of trees, by changing the redox state of any part of the forest, or by changing the pH at some point in the system. Some of this interaction may be physiological in the vegetation, or in the soil microflora, or may be a matter of soil chemis try. Growth rates of the vegetation ma be changed, thus affecting the rates o elemental cycling. Each pollutant ma have separate effects depending upon it chemical and physiological nature, an there may be synergistic effects wit combinations of additives. Some of th major chronic pollutants will be con sidered separately.

Carbon Compounds and Accompanying Oxidants

Carbon additions to the forest ma be important because of the role the play in plant growth and subsequen mineral cycling. Finlayson and Pitt (1976) have reported that carbon ma account for 45% of the mass of smog aero sol. Much of this may be the result o secondary reactions creating carboxyli acids, esters, carbonyl compounds alcohols, peroxidic polymers, long cha alkanes and alkenes, and fatty acids. addition, carbon in the forms of vario compounds is a world-wide atmospher pollutant due to human activities oxidi ing reduced carbon for energy, and indirect effects such as enhanced oxid tion of soil organic matter due to clea ing forestland for agriculture. Th carbon dioxide as a chronic pollutant h been measured by observations at Mau Loa (Hawaii) to be rising at the rate from .35 to 1.79 ppm per year to a lev of 325 ppm in 1974 (Hobbs, et al., 1974 Peterson (1969) in a review stated th carbon dioxide at its present level the atmosphere is still limiting to pla growth and that the productivity plants should increase as the CO_2 conte increases. A resulting increase of pla and forest growth of 5% by the year 20 is a predicted , and this would increa the rates of uptake of necessary grow elements from the soil, thus increasi rates of elemental cycling. This a assumes other elements or requiremen such as water are not limiting to pla growth. On the other hand, reduction plant growth may occur where toxic carb compounds from pollution cause damage tree foliage, thus reducing rates mineral cycling. Ozone produced as secondary product from ultraviolet radi tion on hydrocarbons in the atmosphe may reduce plant growth. Evans, et a (1974) found ozone contents of 0.1 ppm the top of a smoke plume from a fore fire. However plants synthesize meth chloride according to Lovelock (1975 and this may destroy such added ozon The oxidants formed from the organic po lutants introduced to the atmosphere wi have adverse effects upon various ami acids in plants resulting in dama

aagen-Smit, 1958). Fatty acids on ant surfaces may be altered by the nglet oxygen resulting from NO_2, ben-ldehyde, and polynuclear hydrocarbons, creasing saturated acid content of the liage according to Dowty et al. (1973). her oxidants such as peroxyacetyl trate (PAN), hydroxyl OH, hydroperoxyl $_2$, also have similar effects on vegeta-on. Their effects as oxidants are fined by their capability to oxidize dide ion in aqueous solution of potas-um iodide according to Kuntz, et al. 973). Also, their action may be syn-gistic, so that although one or another in low atmospheric concentration the n of the oxidants must be considered in fect on the vegetation. Also, the latile terpenes produced by the forest self must be taken into account, and cording to Rasmussen (1970), as many as)% of the species in some western coni-rous forests may produce such volatile drocarbons.

rogen

Nitrogen as it cycles in the forest in reduced form in the plant and fol-ving mineralization to ammonia in composing detritus in the soil it is dually oxidized to nitrate where it is in taken up by plants to be reduced in ious nitrogen compounds. Nitrogen is ed as a chronic air pollutant as onium, and nitrate nitrogen which also the end product of oxidation of NO by ne. Where nitrogen is limiting in the est as an essential element this uld stimulate forest growth and decom-ition processes provided other ele-ts are not limiting. However, if er elements are limiting this would d to emphasize the other deficiencies. itions as a chronic pollutant should w similar symptoms to those of the ition of nitrogen as a fertilizer. s foliar nitrogen contents should be her. A result similar to this encoun-ed in Big cone spruce foliage in the Bernardino mountains is reported er in this paper.

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The sulfur cycle in forests is such the sulfur is in reduced form in ociation with organic compounds in the nts, but is oxidized upon decomposi-n in the organic detritus returned to soil. The decomposing soil micro-a convert the sulfur to sulfate. The ree to which this takes place depends n the redox potential of the soil. For ple, if it is very low, the sulfur be retained in sulfide form, fre-tly tying up heavy metals.

The forms of sulfur added in chronic atmospheric pollution have been SO_2, $SO_4^=$, with associated cations H^+, NH_4^+, and HSO_4^+ as determined in the pollutant plume from St. Louis Missouri by Charlson, et al. (1973). They found that tropical air masses were dominated by the more acidic NH_4HSO_4 while northern air masses were less acidic and dominated by $(NH_4)_2SO_4$ (1975). Usually the sulfur in the atmosphere will be oxidized to sulfate and this will occur either as ammonium or calcium sulphate dust according to Haagen-Smit (1958), and since trapping surfaces of vegetation are aerobic, any reduced sulfur will be oxidized to sulfate in the foliage.

Since sulfur is an essential element for plant growth, the additions may or may not be deleterious. Actual deleterious effects would occur to trees if sulfur dioxide were the main additive. This would occur only close to the emission source as has happened at Kennett, California; Copper Basin, Tennessee; and Sudbury, Ontario. At greater distance this would be oxidized. Presumably if the pollutant were added in extreme amounts, the titrable acidity produced would break through the soil exchange capacity after depleting other cations present. An example of a simulation of this is offered in table 2 explained later.

Trace Elements as Washout, Particulates, Dusts

Most of the elements other than C, N, and S will be added in dust and rain as chronic pollutants. The particulates in atmospheric pollution contain elements such as lead, sodium, magnesium, aluminium, vanadium, and zinc in Los Angeles type smog according to Finlayson and Pitts (1976). Sedimentary cores taken offshore in the Pacific Ocean by Bruland, et al., (1974), indicated that lead, silver, copper, zinc, chromium, nickel, molybdenum, and cobalt are chronic pollutants in the Los Angeles area. Lead, iron, manganese, nickel, copper and zinc were analyzed in precipitation as common trace element pollutants throughout the U.S. according to Lazarus et al. (1970). Beryllium is common in industrial dusts near sources. The amount of trace element fall out lessens as the square of the distance from sources according to Bertine & Goldberg (1974). Cannon and Boles (1962) found that highways represented linear sources for lead, the amount in vegetation decreasing rapidly with distance from the source. Dedolph et al. (1970) found that this dimunition was logarithmic with distance for particulate lead. However, some elements such as cadmium, nickel, lead, and

zinc may be vaporized at the source and carried longer distances according to Lagerwerff & Specht (1970).

The tracing of input of trace elements in the elemental cycles in vegetation has been attempted by many investigators. Chester and Stoner (1973) used an enrichment factor in which a ratio of the element to iron in the particulate being added is divided by the average ratio of the element to iron in the earth's crust. They found that tin, lead, and zinc most often were the elements enriched by pollution. Peirson, et al. (1974) employed an enrichment factor in the form of the ratio of the element to Scandium content, compared to the same for the local soils. They found the soils enriched for V, Co, Ni, Zn, As, Se, Sb, and Pb this way. Similar enrichment ratios for other pollutants should identify augmentations of the elements in elemental cycles in forests.

The contents of pollutants in the plants should be identifiable by anomalies in composition. Thus, Schacklette and Connor (1973) used the regional variation of vanadium in Spanish moss (Tillandsia) along the gulf coast of the U.S. to identify areas where chronic pollution by airborne vanadium occurs. Contents as high as 560ppm V were found in certain areas, and these were assumed to represent the output from oil refineries using Venezuelan crude oil which is high in vanadium. In soil-vegetation cycling, vanadium is frequently held at the soil-root interface due to immobilization in the oxidized state (pentavalent form). Thus, the redox state of the soil-vegetation system and its components in the forest may determine where a chronic polluting element may be immobilized. Elements undergoing changes in solubility with various oxidation states may be immobilized at various interfaces where pH or Redox change. Chromium, vanadium, manganese, and iron are susceptible to this.

Some of the chronic pollutants added to the elemental cycle of forests may later be released from the forest by vaporization. For example, Curtin et al. (1974) found that tin is transpired in vapors from conifers to the amount of 23-80 ppm in the residue of the vapor. They found that some coniferous twigs contained up to 6-40 ppm tin in the ash. The tin was added as atmospheric pollutant in dust from industrial areas. However, no mention was made of this as being deleterious.

The inputs of dry particulate materials as dusts may be washed off by rain. This washoff may be a major process of cycling of the added element to soils. Carlson et al. (1976) found that a simulated rain removed 45% of an applied aerosol of $PbCl_2$, and that light misty rain is most effective. Heichel & Hankin (1972) found that the particulates in which lead adhered to trees averaged 7 micrometers in diameter. Chlorine and Bromine were the main associated negative elements associated with them. The assessment of the intensity of input of chronic pollutants such as these have been made by analyzing concentrations on tree bark by Lotschert (1977), and Grodzinska (1977). Some of these accumulations are washed down the tree trunk by stem flow and may be accumulated in the soil at the tree base.

POLLUTANT INPUT IN PRECIPITATION

Washout as well as input of element in solution in precipitation is a majo path of input to the elemental cyclin that occurs in forests. For example, th nitrogen content stored in a 1000 yea old redwood forest is about the amoun contributed by rainfall during that tim period (Zinke, et al., 1979). The geo chemistry of precipitation was reviewe thoroughly by Carroll (1962). She foun that the cations which balance the ion in rainwater were mostly basic metalli elements near coast lines or ari regions, but that along the storm vecto from these sources and over regions wit more vegetation, there would tend to b acidification due to less dust or oce aerosols to provide the basic metall cations. The control of wind erosi over the Great Plains thus would tend add to the acidfication of rainfa downwind from the area. However t current emphasis on pollution has add the consideration of sources of anions precipitation that come from burning fo sil fuels. As Carroll (1962) mentione a pH below 5.7 indicates that hydrogen ionizing to meet the necessary balan with anions.

The effect of precipitation inp upon nutrient element cycling in a fore will tend to be specific to the site co ditions. This would be determined by t following local factors: 1. backgrou natural composition of the soil solutio 2. the cation exchange capacity of t soil and the composition of cations occ pying this capacity. 3. the volume water entering as rainfall, 4. the ac base balance of the rainfall, 5. t nature of the vegetation species wi

gard to intensity of cycling basic tallic elements, and perhaps others ique to the site. The effects of input precipitation will most obvious on precipitation will be most obvious on tes with soils having low exchange tter content soils) and with sparse ow growing vegetation (pines, spruces, athland), and in climates with large ounts of precipitation.

FOREST ECOSYSTEM EFFECTS

The mineral cycling in a forest es place in the context of an ecosys- of processes linking the various liv- organisms and the components of the ironment. Chronic atmospheric pollu- n is one of these components. The ments added will be utilized by the ducers in the forest. These are the anisms which carry out the reduction carbon to carbon compounds which prise the forest. This fixed carbon n serves as an energy source for the omposers in the forest which also have uirements for the nutrient elements her in the biomass of the producers or nished directly by the soil. Thus lutant elements will interact in the le between Producers and Decomposers, h storage of elements and possible ks of unavailable material accumulat- in the soil portion of the cycle.

ects of Chronic Pollution on Producers

These effects can range from ancement of productivity to a marked rease depending upon whether the addi- is an element currently limiting wth or is a toxic element. If toxic, effects will show up in foliar dam- or interference with various physio- cal processes. The syposium proceed- edited by Naegele (1973) contains descriptions of these toxic effects. Cune in this publication felt that toxic effects should be specific regard to the Receptor (leaf, tree, rst), the Pollutant, the Event, and Environment. Acute effects are rela- ly easy to determine, as in the death eaves near a smelter releasing SO_2. ously this would decrease the rate of ental cycling at the site along with ief surge of added materials to the as the defoliation took place and es dropped to the soil to be decom- d. Whether this is a loss to the depends upon the capacity of the rlying soil as discussed in relation defoliation by herbicides by Zinke 4). The effects are more difficult ssess in the case of chronic low pollution as discussed by Feder 5). The changes in productivity would need to be statistically significant before and after the initiation of the pollution. Miller (1973) has made an approach to indices of level of chronic pollution in terms of visual characteristics on the trees; needle retention, needle length, needle chlorosis, branch death in the case of ponderosa pine. Foliage composition should indicate such inputs, and a paper by Arkley and Glauser in this symposium covers this. Also an example in the case of Big Cone Spruce foliage is presented in table 1. McBride, et al. (1975) made measurements of actual growth rate retardation of 26% for height and volume growth of ponderosa pine. In agricultural plants, White (1974) found a decrease in CO_2 uptake due to synergistic effects of $NO_2 + SO_2$ when each were present at levels not considered inhibiting to growth. Stimulation of primary producers by pollution is not often reported due to the negative connotation of the term. However, Schnappinger (1975) found an increase in growth due to response to zinc contained in fly ash.

There are numerous variables which may affect the intensity with which a given level of pollutant will affect the producers in an ecosystem. Thus the trapping efficiency of the foliage surface is different for various species as discussed by Zinke (1966), the velocity of the air past the trapping surface as has been evaluated by Hori (1953) and Slinn (1976). Following trapping the material may not be absorbed by the surface as found by Motto (1970). This is partially attributable to the particle size according to Natusch & Wallace (1974). There may be synergistic effects at the foliage surface. Lovelock (1974) has alluded to the possible creation of PAN on foliage surface by the combination of O_3 and hydrocarbons as occurs on drying linen.

Once absorbed by the producer the polluting element will enter the elemental cycle on the site. The disposition from the plant may be not only through leaf drop, but may be by direct root exudation as Olson et al (1962) found with additions of radioactive Cesium added to a tree trunk. However upon being dropped to the soil as detritus or entering in other ways, the polluting element will then be affecting the decomposers in the forest.

Effects of Chronic Pollution on Decomposers

The effects upon decomposers, the soil microflora and fauna that complete

the elemental cycles in the soil, will be variable. As with the producers which fix carbon dioxide, the additives to the site through air pollution may increase or decrease their activities. These organisms require the same nutrient elements as the producers as well as the additional ones of sodium, iodine, and vanadium for the soil fauna. If the pollutants are added in toxic quantities they would presumably retard the decomposition of organic matter in the soil and thus slow or block elemental cycling. They may be sublethal or even mutagenic to these organisms according to Stotzky (1974).

The detritus or litter layer on the forest floor is the first major area of activity of the decomposers. Wittkamp & Frank (1969) found that litter samples impregnated with introduced elements such as Cobalt 60 and Cesium 137 had logarithmic relationship with time in the fraction remaining, and that loss coefficients were different for different elements. These varied with the species of tree yielding the detritus. The storage period of the additive element depended upon relative chemical mobility of the element, composition of other elements present, and the moisture and temperature conditions of the site.

If a pollutant is an element which is limiting rate of decompostion, the effect on the decomposers may be positive. For example leaf litter with too high a Carbon/Nitrogen ratio (nitrogen limiting) decomposes very slowly. Adding nitrogen as a chronic pollutant would accelerate this decomposition and release stored elements more rapidly.

The soil fauna serve a major task in elemental cycling in a forest ecosystem by physically decomposing organic detritus, reducing it in size and increasing surface area to bring about faster rates of fungal and bacterial decomposition. Earthworms of various species were found by Gish & Christensen (1973) to accumulate trace elements from particulate pollution in order of increasing atomic weight: Ni < Zn < Cd < Pb. The soil fauna may serve as a link for transfer of nutrient elements to various predators in the forest ecosystem.

Stotzky (1974) characterizes the soil as both an abiotic as well as biotic sink for pollutants. Ethylene and CO are degraded by soil micro organisms. Fungi in soil metabolize volatiles from plant foliage such as ethane, butane, etc. Thus soil by virtue of the various organisms present has a strong capability to detoxify pollutants. At low concentr- tions pollutants may bring about enrichment of the micro organisms whi can utilize them.

The ultimate role of the decompose is thus to cycle elements from the veg- tation to the soil, usually oxidizi them as energy sources, and ultimate releasing them to the chemical and phys- cal processes of the soil or renew uptake by the roots of the producers.

Entry of Chronic Pollutants into Soil Sinks

The final fate of additives to the ecosystem may be to remain in the soil insoluble form. Thus once processed the decomposers the elements may bec mineral precipitates which may act sinks (Nat. Res. Council 1977). The fluorine added through pollution may precipitated in the soil as insolu CaF_2. Page and Ganje (1970) showed t the top 2.5 cm. of soil was most act in trapping lead entering the so vegetation system in southern Californ Soils sampled in 1967 were compared w previous samples obtained in 1919. average increase of 15-36 ppm l accounted for 1/5 of the lead contai in the 47 billion gallons of gasol which had been burned during the per encompassed. Keaton (1937) added la amounts of lead nitrate to soil (2 ppm) and found that very little (17 p remained in soluble form. Lee & Tal (1973) found it possible to date peri of lead pollution in a peat bog in Gre Britain, finding a peak in 500 A.D. wi the operation of Roman lead mines, an subsequent industrial peak beginn about 1460 AD. Similar but recent h torical evidence of lead collection ecosystem sinks was found in wood cont of lead dated by annual rings by Shepp & Funk (1975).

Soil organic matter genera enhances the role of soil as a sink added trace elements. Furr et al (1 have noted that pH will determine whe soil is a source or sink. Thus, at n tral to slightly alkaline pH; As, B, Co, Cu, F, Fe, Pb, Mn, Ni, Sn, and Z will tend to be immobilized, but Ca, K Mg, Mo, Rb, Se, and Sr may become m available to plants. Thus anything ca ing a change in soil pH may release vious pollutants that had tempora become trapped in the soil as a s Various precipitates such as soil bonates may form, also depending upon

The soil ion exchange capacity retain elements in a form ready to b

Table 1: Big cone spruce foliage analyses across gradients of decreasing chronic pollution intensity.

WESTERN SAN GABRIEL MTNS. Angeles National Forest

Location	Weldon Canyon	Woodwardia Canyon	Cloudburst Canyon	Tie Canyon Summit
NITROGEN				
percent	1.80	1.17	1.31	1.08
rank	93	55	70	30
PHOSPHORUS				
ppm	601	771	656	1545
rank	7	23	12	69
N/P				
ratio	20.2	14.1	10.5	7.0
rank	92	78	61	32

EASTERN SAN GABRIEL MTNS. Angeles National Forest

Location	Lower San Antonio	Camp Baldy	Snowcrest Camp		Big Pines
NITROGEN					
pct.	1.15	1.17	1.05	1.25	1.17
rank	41	45	24	64	45
PHOSPHORUS					
ppm	1093	1432	1432	1235	1592
rank	25	59	59	64	73
N/P					
ratio	10.5	8.2	7.3	8.2	7.4
rank	61	44	36	44	36

SAN BERNARDINO-SAN JACINTO MTNS. San Bernardino N.F. - Cleveland N.F.

Location	Lower Waterman (young)	Lower Waterman (old)	Upper Waterman (young)	Upper Waterman (old)	Crestline	Camp Angeles	Keene	Palomar
NITROGEN								
pct.	2.12	1.80	2.02	2.04	1.22	.99	1.06	1.13
rank	97	92	96	96	52	13	26	38
PHOSPHORUS								
ppm	648	838	1016	1685	1658	1552	1544	1580
rank	1	7	18	81	79	70	69	72
N/P								
ratio	32.7	21.4	19.8	12.2	7.3	6.4	6.8	7.1
rank	99	94	92	70	36	26	31	34
CHRONIC POLLUTION INTENSITY	HEAVIEST		HEAVY		MODERATE-LIGHT		LOW	NIL

Table 2: Simulation of acid rainfall addition by leaching a surface soil developed under the influence of a mature ponderosa pine at the arid limit of the occurrence of the species.
(in milliequivalents per 100 gms. fine earth portion except last column as indicated)

Soil Treatment	Exchange Capacity	Exchangeable Cations Remaining on Soil			H^+ %
		$[Ca^{++} + Mg^{++}]$	$[K^+ + Na^+]$	$[H^+]$[2/]	
Original Soil[1/]	28.80	25.65	2.85	.30	1.0
Leached soils:					
Leachate Composition[3/]					
500 ml H_2O		22.00	1.79	5.01	17.4
+5.71 meq. H^+		18.60	1.02	7.18	25.0
+11.40 meq. H^+		15.00	.77	13.03	45.3
+17.09 meq. H^+		10.30	.38	18.12	63.0
+22.9 meq. H^+		9.00	0.00	19.80	68.8

1/ Fine earth portion, 0-2.5 inch sampling horizon.

2/ Difference between the sum ($Ca^{++} + Mg^{++} + K^+ + Na^+$) and the Exchange Capacity.

3/ The H^+ was added as 0.1N HCl to the 500 ml of distilled water, since 1 ml of 0.1N HCl = 0.1 meq. H^+.

recycled back to the living organisms on the site, and also keep them from leaching away from the site. Depending upon this capacity, elements added through chronic pollution may be retained in the elemental cycle of a forest provided they are not trapped in a sink or leached away.

FOLIAGE ANALYSES INDICATING POLLUTION

The effect of chronic air pollution of the type typical of the Los Angeles - San Bernardino basin on foliar analyses of the Big Cone Spruce (Pseudotsuga macrocarpa (Vasey) Mayr) was determined. Samples of the foliage were gathered throughout the range of the species, and also on gradients of elevation or distance from the areas typified by "smog" to areas relatively free of "smog". Analyses were made of 9 major elements in the various age classes of the foliage. The elements most obviously related to the intensity of the smog and their rating in a cumulative probability distribution from lowest to highest value ar shown in table 1.

Nitrogen content of the foliage an the ratio of nitrogen to phosphorus con tent were the most obvious indicators o the effect of chronic air pollution o the Los Angeles type. Where there wa ambiguity in the nitrogen values as i San Antonio Canyon, the nitrogen to phos phorus ratio was the best indicator i this species.

SIMULATED ACID RAINFALL LEACHING

A laboratory experiment was cor ducted in which samples of a nearl cation saturated soil under the influenc of ponderosa pine were leached with solı tions containing successive increments (H^+ The soil samples were obtained at tl lower rainfall limit of ponderosa pi where the soil was most likely to base saturated. Five seperate ten gr samples of this soil were leached solutions which were respectively 500 of distilled water, and solutions

rhich increments of H^+ as HCl equivalent ;o 20%, 40%, 80%, of the exchange capa- ity of the sample were added. The esults presented in table 2 show the eaching of the exchange complex of soils hat takes place with added increments of cation. Presumably the additions of ncrements of H^+ in acid rainfall would ave similar effects which would have to e considered in the context of other ations being cycled by the forest, and y the composition of cations already on he exchange complex of the soil. Follow- ng this leaching, each soil portion was nalyzed for remaining exchangeable etallic cations.

These data show that given the sto- iiometry of the leaching of cations from ie soil exchange complex by H^+ the ffects of increments of acid rainfall to given soil may be simulated with solu- .ons having compositions similar to that the rainfall. Also, as the increment H^+ in the precipitation increased, ther because of concentration or of lume of rainfall leaching the soil uld tend to become hydrogen saturated, splacing basic metallic cations in pro- rtion. In the forest situation these uld be leached out of the soil profile a base saturated soil, or taken up by te vegetation.

CONCLUSIONS

This review of the literature and te presentation of some original work is aplicable to the effect of chronic air pllution on mineral element cycling of frests. The literature is general, ilustrating processes, but is not site secific except for the location of the sidies. Since effects at any specific ste may be in small increments each yar, but severe in cumulative effects oer a number of years, a major remaining pblem is to find ways of determining se specific indications of detrimental eects of such chronic pollution. Some ptinent conclusions from the literature reviewed in this paper are:

1. The forest vegetation as is true of ar vegetation requires many essential gowth elements which it will cycle in acition to others mobilized by local mieral weathering or input through pre- ciitation.

2. To the extent that chronic pollution ads elements normally required by plnts, or chemically mobile in the plnt, these will be cycled much as the oters on the site.

3. The forest is created in a vast reduction reaction wherein CO_2 is reduced to organic compounds by Producers in the ecosystem, and subsequently oxidized in energy releasing steps by these plants or by the Decomposers in that ecosystem.

4. The cycling of elements takes place in the context of these redox reactions, and those elements which change state with redox potential change are usually in the reduced form in the producer vegetation and subsequently oxidized in energy releasing steps by these plants or by the decomposers on the site.

5. Chronic air pollution additives to the forest affect the cycling of elements not only by direct additions of the polluting elements to the cycles, but also by affecting the redox status of the absorbing plant tissue, and other portions of the soil-vegetation system.

6. Concentration points and sinks for the elements added in chronic pollution exist in the various parts of the vegetation, the surface detritus on the soil, and in the soil capacities for absorption on ion exchange, hydrous oxide complexes, and as insoluble precipitates.

7. The effects of chronic pollutants added to a given forest and its elemental cycling processes will be highly site specific; depending upon climate, degree of weathering development of the soil, the type of minerals from which the soil is forming, the characteristics of the forest species and their stocking densities, the topographic situation with regard to airflow, and the nature of the pollutant.

8. Local site specific indicators of intensity of pollution effect may be visual as in appearance and size of foliage, foliar analyses for pollutant elements and their ratios to background site elements, and soil assessment of capacities to absorb the added elements.

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Forest Genetics and Air Pollutant Stress[1]

Stefan Białobok[2]

Abstract: The breeding of trees, particularly conifers, for cultivation in regions under the influence of industry is of considerable economic importance. The role of genetic polymorphism in the process of adaptation to such environments is discussed. Results are presented of research on the genetic variability in Scots pine populations growing under the influence of industry and in regions free of gaseous pollution. Methods of selecting tree populations tolerant to industrial emissions are discussed aimed at the identification of genetic markers of tolerance.

In order to reduce losses in forest ecosystems caused by industrial emissions attempts were made to determine the sensitivity of trees (depending on their genetic properties) to acute injury of the assimilation apparatus by the most common gaseous pollutants. The degree of plant injury by gases is dependent also on the system of ecological factors operating in the environment.

GENETIC VARIATION OF TOLERANCE BETWEEN AND WITHIN SPECIES

So far a wide scale of genetic variability was observed within various species of trees and shrubs in their sensitivity to airborne pollution. The results listed in reviews (Davis et al., 1976, Bialobok 1979) are only approximate. It appears that most tolerant are some species of broadleaf trees. Coniferous trees which are of greater economic importance are generally characterised by low tolerance.

It was also found that there is genetic variability in response to SO_2, O_3 and HF within one population of Pinus sylvestris, P. strobus, P. ponderosa and within Picea abies as well as in some species of broadleaf trees (Gerhold et al., 1977). The greater tolerance Scots pine and Norway spruce to the air polluti within a population is sometimes associated wit the greater resistance to low temperatures dise and a xerothermic adaptation (Bialobok, 1979). suggestion also exists that the cause of tolerance to some gases may depend on mechanisms tha reduce the access of gases to the plant organis (Gerhold et al., 1977).

However, it has been experimentally establis or deduced from reliable evidence that there exist genetic mechanisms conditioning higher tolerance to industrial emissions (Niemtur, 197 The latter investigator studied 58 progenies of Scots pine from 4 provenances obtained from see collected on remnant living trees in the highly polluted conditions of the Upper Silesian industrial region. He has shown that these progenie have a greater tolerance than those collected from trees growing beyond the range of polluti

POLYMORPHISM AND ITS ROLE

Studies on the genetic variability of enzyme in forest trees developed strongly after Stern (1974) pointed out the great importance of genetic polymorphism for the development of ecolog ical genetics, forest genetics and tree breedi

Thanks to this method it is possible to recognize that genetic structure of a populati (allele frequencies and degree of heterozygosi in space and time, to conduct studies on inher- ance and linkage, to determine the genetic dis

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between individuals and populations, to identify mechanisms of adaptation to an environment and to employ it in practical forestry.

Polymorphism of forest trees which are long-living organisms represents adaptive strategies of populations to a changing environment (Stern et al., 1974). In this genetic system heterozygotes are favored and thus the population is capable of existing in a heterogenic environment surviving numerous and major changes.

Tree populations in industrial regions grow under similar conditions as the herbaceous plants that colonize mine spills having high concentrations of heavy elements (Pb, Zn, Cu). This phenomenon Stern (1974) also considers as being a good example of the developing polymorphism.

In conditions where at least a part of the trees can survive in an industrial environment that has not been too strongly polluted, the population adopts the optimal strategy in reaction to the changes taking place. This, of course, is the result of the evolutionary adaptation process to the new environmental conditions where the genetic system is under a constant selection pressure. Tolerant genotypes appear to have a certain level of fitness in the industrial environment. What is most important to us is that the drastic changes in the industrial environment should not exceed the level of genetic flexibility of the populations of the most important forest forming species. In the acute conditions of change in an industrial environment, the coded genetic system within a population, that conditions its adaptive capacity, gradually ceases to operate once the potential of individual genotypes for adaptation has been surpassed.

GENETIC VARIABILITY OF ENZYMES IN SCOTS PINE POPULATIONS

The use of electrophoretic analysis of enzymes for the identification of variability determining genetic tolerance to industrial pollution is so far only in an introductory phase. The results obtained so far are encouraging. The studies conducted on Scots pine are treated only as a model.

Mejnartowicz (1978) has studied the variability of izozymes of leucyloaminopeptidase (LAP) and acid phosphotase (APH) in 19 populations of Scots pine from the whole range of the species in Eurasia. The Poland populations were chosen from regions under industrial influence and from regions beyond pollution. In all the populations APH was coded in locus B with 15 alleles, and there was considerable polymorphism in the studied populations, and LAP was coded in 2 loci, LAP-A having 5 alleles and LAP-B 6 alleles.

It is interesting that the population of Scots pine from Babki (central Poland--strong industrial pollution) has had the lowest degree of heterozygosity on locus LAP-A, h=0.1124 and the highest value in LAP-B, h=0.3970. Among individuals sensitive to SO_2 the genotype APH-B4/B6 dominated and among individuals tolerant to this gas the allele APH-B5 appeared commonly (Mejnartowicz, 1977-78). Szmidt (1978) when studying the genetic polymorphism of catalase in three populations of Scots pine from industrial regions and 5 populations from regions free of pollution, has found 7 phenotypes of the catalase. When comparing the populations on the basis of heterozygosity he has shown that populations from regions free of pollution were characterized by greater participation of homomorphic individuals of the type C-1/C-1 compared to populations under the influence of emissions.

Mejnartowicz, et al., (1978) having taken material from plus trees in a Scots pine seed orchard established a lack of correlation between the degree of heterozygosity of trees in LAP loci and the degree of their sensitivity to the action of SO_2 in a laboratory test.

These introductory results indicate that there is differentiation in the frequency of some alleles in a population depending on the influence of industrial emissions. The important thing is that an enzymatic marker be found for tolerance which would be independent of environmental influences.

INHERITANCE OF TOLERANCE TO INDUSTRIAL EMISSIONS

Not many investigators have attempted determining in generative progeny the combining ability, heritability and repeatability of tolerance to industrial emissions. In the case of Scots pine heritability and repeatability of tolerance to O_3 is to be found under a low or medium genetic control. However, some provenances have a higher heritability of tolerance to O_3. Needle injury in these pines was positively correlated with the injuries caused by SO_2 (Gerhold et al., 1977, Demeritt, 1977). Bialobok et al., (1978) have also found a significant correlation between the degree of needle injury on mother trees and on their progenies following treatment with SO_2. However, these correlations were not found following treatment with O_3 or a mixture of O_3 and SO_2.

The selection of tree individuals tolerant to industrial emissions is being done by the relatively simple methods of mass selection, without understanding the genetic basis for the population structure. This selection is usually being conducted on seedlings in laboratory conditions. Sometimes positive results were obtained for the practice which with some probability are being utilized in establishing tree plantations or producing trees for ornamental purposes (Demeritt, 1977).

So far it was not possible to solve the problem of breeding various pine species for cultivation in forests under the influence of industrial emissions, and there is no cheap way of propagation of selected individuals.

Gerhold, (1977) has discussed several methods of breeding trees more tolerant to industrial emissions, in which the use of seeds orchards established from tolerant clones is envisaged.

It appears, however, that it would be valuable to expand the investigations of genetic variability of enzymes in populations of coniferous trees endangered by industrial pollution. We have considerable information already on the course of metabolic cycles in the tree organism exposed to the action of some gases. I believe these two sources of information could be combined, (biochemical genetics and metabolic changes) in order to identify the enzymatic genetic marker that would be useful in the selection of tolerant populations.

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Interactions of Air Pollutants and Plant Disease[1]

Michael Treshow[2]

Abstract: Each interaction between an air pollutant and disease is unique. Pollutants may mitigate disease response or intensify it; and the presence of certain diseases can modify the plants response to a pollutant. Air pollutants can act directly on a fungus or bacteria inhibiting parasitism. They may also act most strongly on the host, modifying its physiology and rendering it either more or less sensitive to a plant pathogen. Where the plant is weakened by the pollutants, it tends to be more sensitive to weak pathogens, but less sensitive to obligate parasites. Where the pollutant physically injures the host, infection may be facilitated. Pollutant interactions have been demonstrated both in the laboratory and the field at ambient pollutant concentrations. Interactions between pollutants and abiotic stress are particularly critical. Water regime, temperature relations, mineral nutrition and other parameters of the physical environment play a major role in the expression of air pollution injury.

Air pollution can kill plants. Even when the ncentrations of an air pollutant are not rectly lethal, they may be harmful, adversely fecting growth, reproduction and myriads of her biological processes (Miller and McBride 75). One such process is the interaction that sults between the pollutant and plant thogens.

There are many ways in which such interctions might take place. But do they? The most vious would be if the pollutant directly fected the fungus, virus, bacteria, insect or other pathogen. If some stage of an organism's life cycle, or some stage of parasitism, were adversely impaired by a pollutant, the pollutant essentially would be acting as a fungicide, bacteriocide or other biocide and could be expected to bring about some degree of control.

The second way an air pollutant might act would be in adversely affecting the growth or reproduction of the host plant and thereby influencing its suitability as a host. There are two ways in which such action could be brought about. Most apparently, the pollutant might cause some physical injury to the plant leaving lesions that could serve as infection courts for a fungus or bacteria. Or, the plant might simply be weakened, thus lowering its resistance to a prospective pathogen. Presumably the weaker pathogens, the facultative parasites, would benefit most by such

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conditions. Obligate parasites, on the other hand, preferring a vigorous host, might respond quite differently and their development might even be discouraged in the weakened host.

Conversely, the impact of various diseases or plant stresses on the plant's response to air pollutants has also been considered. It should be quite apparent that adverse climatic or edaphic factors might affect a plant's sensitivity to a pollutant, but the presence of certain biotic diseases may also increase or decrease a plant's sensitivity.

A major question is not so much do such interactions take place, but what concentrations of an air pollutant are required to precipitate such effects, and how widely do such concentrations occur?

Many of the interactions that will be discussed have been demonstrated under laboratory conditions, often at pollutant concentrations known to be fairly widespread. Some of the interactions have been observed in the field.

The literature treating such air pollutant-plant pathogen interactions has been reviewed most recently in 1978 (Laurence), 1975 (Treshow), and 1973 (Heagle); it is not the intent of this paper to once again provide an exhaustive review of this literature. Rather, I should like to first bring the literature up to date, briefly including that delving into the interactions of abiotic stresses on pollutant effects, and discuss the implication and possible practical relevance of such interactions, especially concerning forest ecosystems. Primarily I should like to develop some of the principles in pollutant-pathogen interactions.

INFLUENCE OF POLLUTANTS ON DISEASE EXPRESSION

Sulfur Dioxide

There is no question that sulfur dioxide interacts with fungi, suppressing their growth and acting fungicidally. The only question concerns the SO_2 concentrations at which such interactions occur.

A few examples exist where SO_2 has acted in such a way in the field, limiting the development of certain plant diseases. The examples provided by Scheffer and Hedgcock (1955) in which parasitic fungi generally appeared to be retarded or inhibited near smelters where SO_2 was present is most often cited (Treshow 1975). Suppressed disease development was especially apparent where rust fungi, *Melampsora* and *Puccinia*, or needle cast fungi were involved. Linzon (1973) also discusses the reduced heart rot and blister rust (*Cronartium ribicola*) near a smelter.

But such incidents are becoming more infrequent as ground level SO_2 concentrations become reduced by modern control technology or use of tall stacks. Higher SO_2 concentrations, often exceeding 1 ppm for extended periods, now tend to be of only historic record. We are now interested in the possible impact of SO_2 concentrations in the 0.1 to 0.5 ppm range or even lower in cases of prolonged duration. Where such concentrations still exist near smelters, power plants, or large urban centers, some pollutant-pathogen interaction might be sought.

There is some evidence from laboratory and field research that certain pathogenic fungi respond to SO_2 in this concentration range. Weinstein and others (1975) for instance, have demonstrated that SO_2 concentrations of 0.14 to 0.15 ppm, continuous for 7 days, while not visibly injuring plant foliage, affected the bean rust fungus, *Uromyces*. The incidence and severity of the rust as measured by the abundance of uredia was decreased as were both the size and percent germination of the uredospores. Hence the reproductive potential of the pathogen was reduced. The results suggested that the effect on the pathogen was indirect; perhaps involving an SO_2-induced chemical change in the resistance of the host and its suitability as a habitat for the fungus. The authors speculated that production of phytoalexins or supply of metabolites might have been altered, or compounds derived from SO_2 might have accumulated.

One of the most comprehensive field studies of the interactions of industrial air pollutants, especially SO_2, with plant disease was conducted by A. Grzywacz and J. Wazny (1973). The study was notable since it dealt with economically significant diseases of a coniferous forest, specifically Scots pine (*Pinus sylvestris* L.). Interactions with six fungi were considered: *Armillaria mellea*, *Fomes annosus*, *Lophodermium pinastri*, *Microsphaera alphitoides*, *Melampsora pinitorqua*, and *Cronartium flaccidium*.

In an overall study, comparisons were made of disease presence in industrial areas and forests throughout Poland. In a more detailed approach disease presence was compared at increasing distances from an industrial town, Torun, with one major SO_2 source.

The general comparisons showed that *Armillaria* was present in 3.7 percent of the trees in the area damaged by SO_2 compared with only 1.38 percent in all forests. *Lophodermium* also tended to be more serious in the industrial areas, but the results were indefinite. This was consistent with earlier findings of Donabauer (1966) that high SO_2 concentrations increased the intensity of *Armillaria* root rot.

Fomes showed the reverse trend and occurred

n 0.87 percent of the areas affected by indus-rial pollution compared with 1.5 percent in the ountry as a whole. *Fomes*, as in the overall tudy, was least prevalent in areas of highest O_2 concentrations. Grzywacz and Wazny (1973) ound that stumps close to the SO_2 source were ound. Related, decomposition fungi were also ess abundant closest to the source. Only 50 ercent of the stumps showed signs of decom-osing, and 10 percent strongly decomposing, mpared with 30 percent strongly decomposing rther out. However, Gryzwacz (1978) later eported that stands influenced by air pollution re more subject to decomposition by brown, ite or soft rot fungi. Sufficiently high SO_2 ncentrations might suppress the fungal growth rectly. Such was the case where Mejstrik 978) showed SO_2 concentrations as low as 84 /m^3 (.03 ppm) inhibited growth of *Flamulina lopes*, *Nematoloma fasciculare*, and *Pleurotus treatus* from 34 to 39 percent.

Lophodermium injury was least significant ar the SO_2 source. At distances beyond 1 km jury appeared on up to 70 percent of the edles. There was a slight decrease beyond is. When annual SO_2 concentrations averaged low 0.2 ppm, disease incidence was essentially e same as in the control group. Fungus devel-nent was noticeably affected. Within 1 km, production was largely by pycnidia; further stant, apothecia were common. The numbers of edles with both the sexual and asexual stages creased with distances. Closest to the SO_2 urce, apothecia were only 15 percent the ngth of controls deformed, collapsed, under-veloped, closed or even dried up and with ill-veloped asci. Chiba and Tanaka (1968) however ported high SO_2 concentrations of 2 ppm for 14 rs caused increased infection of injured pine edles (*P. densiflora*) by *Rhizosphoera khoffii*.

Weidensaul and Darling (1979) inoculated ts pine seedlings with the fungus *Scirrhia cola*. The plants were inoculated either 5 s before or 30 minutes after fumigation for 6 rs with 533 $\mu g/m^3$ (0.20 ppm) SO_2). After 8 ks, the seedlings inoculated 5 days before igations had more lesions incited by the gus than those inoculated 30 minutes after igations in the control group. It was postu-ed that since the needle blight fungus pene-tes through the stoma, the ability of the SO_2 keep the stoma open facilitated entry of the gus.

The pollutant-disease interaction may vary h the host species. Ham (1971) found that n loblolly pine served as the host, the brown fungus (*S. acicola*) was not measurably cted by SO_2 in the 0.5-0.9 ppm range for 2-3 s even when SO_2 caused visible injury.

imulated rain, acidified with sulfuric acid also been shown to influence pollutant-pathogen interactions (Shriver 1974). Although not involving forest species, the work did demonstrate the way in which plant species might be affected.

Kidney beans (*Phaseolus vulgaris* var. red kidney) and willow oak (*Quercus phellus*) were exposed to simulated rain acidified to a pH of 6.0 or 3.2 for 10 minutes each day for 30 to 60 days. The acid "rain" caused an 86 percent inhibition in the number of telia produced by *Cronartium fusiforme* on willow oak, a 66 percent inhibition in the reproduction of the root knot nematode (*Meloidogyne hapla*) on beans in the field, and a 29 percent decrease in the percent of leaf area of field grown beans affected by *Uromyces phaseoli*. Exposures to pH 3.2 "rain" completely destroyed the integrity of the cuti-cular waxes in both oak and bean. Exposures to the pH 6.0 solution did not visibly alter the cutin. Shriver postulated that damage to the cutin facilitated leaching of carbohydrates from the leaf including those that might inhibit hyphal growth of *Botrytis cinerea* thus predis-posing plants to infection.

This is consistent with the findings of F. A. Last and O. D. Fowler at the Institute of Terrestrial Ecology at Penicuik, Scotland (per-sonal communication) who showed that the cuticle of Scots pine was gradually broken down by low concentrations of SO_2.

Sulfur dioxide, perhaps largely as acid rain, may have an effect on soil microorganisms (Wainwright 1978). Sulfur-oxidizing micro-organisms, including *Alternaria tenuis*, *Auriobasidium pullulans* and *Cephalosporium* sp., were isolated from leaves, litter and soils polluted with high levels of SO_2. The predomi-nant autotroph on leaf surfaces was *Thiobacillin thioparis*.

Hibben and Taylor (1975) found that SO_2-pathogen interaction depended on the infection stage. Conidial germination and the appres-sorial stages of *Microsphaera alni* were most sensitive to SO_2. Since infection was not reduced when leaves were previously fumigated, the effect was thought to be mostly fungicidal.

Ozone

There is considerable evidence that photo-chemical pollutants, most notably ozone, affect plant pathogens and fungus-host interactions. The interaction may be positive or negative depending on the O_3 concentrations and the O_3 sensitivity of the host.

In one such study, Miller and Elderman (1977) showed that fumigation of ponderosa and Jeffrey pine seedlings with ozone enhanced infection by *Fomes annosus*. Average infection of the two

species increased from 57 percent to 78 percent when the seedlings were exposed to 431.2 $\mu g/M^3$ (.25 ppm) ozone. They also found that ozone injury increased the susceptibility of pine stumps to colonization by *Fomes annosus*. In the laboratory, wood from trees slightly damaged by oxidants was more decay-susceptible than wood from severely damaged trees.

Far more research has involved powdery mildew (Heagle and Strickland 1972, Heagle 1975, Scheutte 1971), and the negative impact of ozone on disease. Even ozone concentrations in the 5 to 50 pphm range reduced infection when conidia were exposed. According to Scheutte, appresoria formation was largely affected. Also, some epidermal cells, hypersensitive to ozone, were killed thereby reducing infection. Eight hour exposure to 50 pphm ozone reduced formation of secondary hyphae 66 percent and 4 hour exposure reduced 41 percent. Ozone impaired formation of the penetration peg thus inhibiting subsequent development of a functional host-parasite relationship.

While ozone impacted certain critical stages of infection under controlled conditions, in the field such effects would be less apparent since all stages of parasitism would be present simultaneously.

Interactions of facultative parasitic and saprophytic fungi with their hosts may also occur and are most pronounced when the plants are weakened or injured by ozone (Manning 1975). Obligate parasitism appears to be retarded by ozone and ozone-injured host tissue. Colonization of ozone-injured white pine needles by *Lophodermium pinastri* was reduced while colonization by the saprophyte *Aureobasidium pullulans* was increased. Ozone-injured lilac leaves were rarely infected by powdery mildew *Micosphaera alni*.

When the fungus is especially sensitive to ozone the impact may be mostly fungicidal thereby reducing infection. Sporulation and germination of the weak parasite *Botrytis cinerea* was significantly inhibited by 2, 6 hour ozone exposures at a concentration of 30 pphm (Krause and Weidensaul 1978). There was also less infection, based on total lesion area, when plants were exposed to 15 pphm. Ozonation of conidia produced *in vivo* and *in vitro* decreased germination of conidia, germ tube length, and pathogenicity. The authors postulated that the mode of action was to alter the permeability of the conidia membrane. Ozone may increase the conidiophore respiration causing prematurely-formed and non-viable conidia. Ozone also may inhibit, directly or indirectly, enzyme activity of the fungus and cause less maceration of the host cells resulting in a decreased infection.

Curtis and others (1976) found that plants exposed to ozone produced peroxidases and isoflavonoids that are toxic to microorganisms. According to Laurence and Wood (1978), ozone inhibited infection of soybean by *Pseudomonas glycinea* presumably because of a bacteriostatic compound, possibly an isoflavinoid compound, produced in response to ozone.

Fluoride

Fluoride is accumulated in the foliage of plants and affects many metabolic processes. Consequently, it is reasonable to presume that pollutant-pathogen interactions can be influenced, perhaps to a greater extent than with any other pollutant. This was confirmed with viruses by some of the early work reviewed by Heagle (1973) and Treshow (1975).

Host-fluoride interactions also have been demonstrated for fungi (McCune and others 1973) although not on forest species. Studying the interactions of 7 to 10 $\mu gF/M^3$ with 3 diseases of bean and 2 diseases of tomato, HF consistently reduced uredial formation as the foliar fluoride content increased. Tender green beans exposed to HF and inoculated with powdery milde conidia developed fewer foliar lesions than non fumigated control plants; 4.4 compared with 48. on fumigated leaves having an average of 399 pp F. Powdery mildew was reduced proportionate to the length of the exposure period. Early bligh lesions on tomato were similarly reduced by the presence of fluoride.

INFLUENCE OF DISEASE ON POLLUTANT SEVERITY

Not only may the presence of a pollutant influence pathogenicity, the reverse may be true--presence of diseases influence the degree of pollutant injury. This has best been demonstrated with viruses. None of these involved forest species though, and there has been no ne results published since last reviewed by Laurence (1978).

Also, in the forest, variation in pollutant resistance among individual trees would far exceed any disease and pollutant interaction, and any impact of a disease on pollutant severity probably wouldn't be measurable.

ABIOTIC STRESS

Severity of air pollution injury is determined not only by the dose of the pollutant to which plants are exposed but on the predisposi tion of the plant. Predisposition is determin by any environmental parameter to which the plant is subjected. It has been discussed mor in passing than as a major concern (Heck and others 1965, Heck 1968, Treshow 1970, Taylor 1974), but the interactions of abiotic stress disorders with any pollutant is far more

significant than with biotic pathogens. Moisture stress, the light regime, edaphic factors and temperature relations all influence the sensitivity of plants to every pollutant.

Unusually high or low temperatures prior to exposure tend to reduce plant sensitivity to ozone, for instance. A normal high light intensity renders plants more sensitive. High humidity, by encouraging open stomates, also increases sensitivity. In dry air, plants are more tolerant of ozone than at higher humidities, and PAN injury is most severe in the Los Angeles area when the relative humidity exceeds 0 percent.

Any factor favoring moisture stress and educed water uptake would cause stomatal cloure and favor resistance to pollutant uptake nd injury. In this way, plants in more saline oils are more tolerant of certain pollutants Oertli 1958) and there is little to no ozone or AN injury when soil moisture is deficient.

Ozone injury may be negligible when ambient ir temperatures during and after exposure are elow 90° F., yet may be severe when temperaures exceed 90° F. (Taylor 1974).

Effects of low atmospheric and soil moisture n tolerance or sensitivity of plants to SO_2 njury are well known; suffice it to note that lants are far more sensitive under higher oisture conditions.

Mineral nutrition also plays a role in pollunt sensitivity. Vegetable crops are known to most susceptible to ozone when nitrogen trition is adequate although some reports ggest injury is greatest when nitrogen is w. Sulfur dioxide sensitivity is reported to greatest with increased sulfur nutrition. omatal behavior may be involved since a deficncy of nitrogen, potassium or phosphorus may decrease stomatal opening. Plants low in sulfur d the lowest stomatal capacity, thus less pacity for gas absorption (Leone and Brennan 72).

Toxicity from heavy metals also plays an teresting role with air pollutants. Ormrod (77) has found that ozone toxicity was enhced on pea plants growing in elevated concentions of cadmium or nickel. However, when cdmium concentrations were sufficiently high to aersely affect growth,100 µmol of $CdSO_4$, then one injury was less than that of control pnts.

Harkov and others (1979) found that the aunt of ozone injury depended on the cadmium a ozone levels as well as other environmental cditions. Where environmental conditions were n conducive to ozone injury (e.g. bright slight), cadmium had little effect on the aunt of leaf damage. When environmental conditions allowed only slight to moderate foliar injury on tomato leaves, damage was enhanced by cadmium treatment especially at higher concentrations.

Along the same line, low concentrations of SO_2 affected metal uptake, increasing zinc and cadmium susceptibility of bean plants. Foliar injury caused by heavy metals was significantly enhanced by SO_2 (Krause and Kaiser 1977).

Lamoreaux and Chaney (1978) also found significant interactions between cadmium and SO_2. While cadmium or SO_2 alone reduced net photosynthesis and transpiration of excised silver maple leaves, the reduction in cadmium-treated leaves was greatest in the presence of SO_2.

CONCLUSIONS

Virtually every environmental parameter, biotic and abiotic can interact with air pollutants to aggravate or mitigate the extent of pollution damage. The significant question then becomes, to what extent and at what concentrations? Is the net impact real, and if so, how meaningful is it under field conditions?

All pollutants don't interact the same. Sulfur dioxide, for instance, appears primarily to act fungicidally reducing disease and decomposition activity. It is also postulated though that SO_2 induces chemical changes imparting resistance to certain pathogens. Ozone tends to act more on the host, weakening it and accentuating disease activity. Research with vegetable crops at low ozone concentrations indicate that pollutant-disease interactions do occur with some diseases and very likely occur in forest stands weakened by photochemical pollutants. Ozone has increased susceptibility to Fomes and rendered trees more susceptible to decay. Each interaction is unique since every fungus has its own sensitivity as does each plant. Thus the potential for interaction is enormous.

Pollutants such as fluoride that accumulate significantly in plants would likely have the greatest interaction. While the trend is to inhibit disease development, the concentrations at which this has been demonstrated are now infrequent in the field.

The significance of abiotic stress and pollutant interactions is often taken for granted, but it should be emphasized that this is of paramount importance. Climatic and edaphic factors are often determinants in the expression of pollutant damage. While the abiotic environment strongly influences the severity of air pollution damage, air pollutants influence the severity of plant diseases caused by biotic pathogens. It would appear that as in all life systems, every environmental parameter has some influence on every other. In the case of

pollutants and pathogens, this interaction can be significant.

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Studies on Relationship Between Air Pollutants and Microorganisms in Japan[1]

Kiyoshi Tanaka[2]

Abstract: A review of the literature on the interaction of air pollutants with parasitic and epiphytic microorganisms is presented with a brief outline of air pollution problems in Japan. Some fungi such as Cercospora sequoiae, Pucciniastrum styracinum, Puccinia kusanoi, Melampsora coleosporioides, Trichoroma matsutake, and some epiphytic bacteria disappeared in the areas affected by air pollutants, and Rhizosphaera kalkhoffii increased its activity due to SO_2 in the air.

Fungi, bacteria, viruses and nematodes, as well as insects are all responsible for bringing a certain species of higher plants into equilibrium with its environment (Treshow 1968). The effect of air pollutants on population trends of various microorganisms, therefore, is extremely important in all ecological systems. Further, air pollutants may affect plant disease development in different ways. Pathogenicity may be influenced through a direct effect of the pollutants on the parasite, or the effects may be indirect through pollution-induced changes in physiology of the host plant (Heagle 1973).

Prior to 1960's, the interaction of microorganisms with pollutants in the air had received limited attention in Japan. But during the past decades, a series of experiments has been conducted in order to explain the effect of air pollution on disease development, and only recently, some attempts have been made to understand the change of populations of microorganisms for use as biological indicators of air pollution.

From the beginning of recognition of the significant and sometimes devastating effects of air pollutants on vegetation, plant pathologists have been confused with the similarities between the symp of many types of pollution damage and those of fectious diseases sometimes leading to incorrec diagnoses. Fortunately, each of the common air pollutants produces a characteristic injury pat and the sensitivity of many species differs suf ciently for the trained eye to determine the ca ative agent (Adams and Salzbach 1961).

This paper will review the literature on: 1) modification of parasitism and the population changes of epiphytic microorganisms induced by pollutants; 2) attempts to make reliable guide distinguishing among symptoms caused by air pol tants and parasites, and those occasionally pro duced by saprophytic fungi. These subjects are considered in conjunction with a brief outline air pollution effects on forest ecosystems in

SULFUR DIOXIDE (SO_2)

In Japan, towards the end of 19th century, pollution was reported to be harmful to forest around ore smelters that emitted large amounts SO_2. Plume behavior resulted in pollutants dis sion in the surrounding area, killing all the etation (mainly Cryptomeria japonica D.Don and Pinus densiflora Sieb. et Zucc.) and causing e sion of topsoils following the death of the pl (Doi 1919). The concentration of SO_2 of the s was reported to be 1 ppm at 1 mile from a larg smelter located in Ashio, Tochigi Prefecture, occasionally reached as high as 8 to 10 ppm at ground level (Doi 1919).

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Raising the height of stacks in order to reduce ә concentration of SO_2 at the ground level was ә first and primitive control measure, new tech- logy involves the installation of sulfur recov- / devices. In 1915, one ore smelter in Hitachi, araki Prefecture, built a new stack on a hill sing about 350 m above sea level; the stack was arly 170 m high, so that the smoke was discharged an elevation of approximately 520 m. Although elter smoke is released from high stacks, it ads to diffuse rather slowly, and the SO_2, there- e, **reaches the ground in harmful concentrations** en after a considerable length of time and dis- ace. Observations made three years after the placement of stacks revealed the fact that the erity of damage in the area near to the smelter markedly reduced,while the total damaged area reased as large as 24,000 ha (Doi 1919).

The reduction of the concentration of SO_2 in the a in the vicinity of the ore smelter on account the change of stack height was good enough to ume the seedling production of Cryptomeria onica in nurseries. Kaburagi (1930) was im- ssed with the absence of a needle blight of ptomeria japonica caused by Cercospora sequoiae . et Ev. in the nurseries located in the recov- d area close to the higher stack. The needle ght is one of the most destructive diseases in est nurseries producing Cryptomeria seedlings, has spread rapidly throughout Japan except Ho- ido. The causal fungus was introduced from th America in the end of 19th century, and Iba- i Prefecture including the ore smelter is con- ered to be the epicenter of the introduced dis- (Ito 1976). Kaburagi (1930) suggested that a ong correlation existed between SO_2 in the air the absence of the disease. This is believed e the first report on the effect of air pollu- n on diseases caused by parasites in Japan. Ka- agi's observation is strongly supported by the lowing hypotheses that: 1) SO_2 might act direct- upon the fungus on the surfaces of host plants; 2) the reduction of disease severity resulted decrease of inoculum for new infection.

ome of the acute type of damage by the emis- s from smelters still continues in areas near ources. **In the 1960's, widespread SO_2 air pol- on damage to ornamental trees had become appa-** to the public; this increase was due to urban- ion and industrialization. The one most appa- episode in and around Tokyo was the stunting death of a large number of Zelkova serrata Mak., ly used as shade trees throughout Japan (Yambe).

ith a considerable increase in public awareness he chronic type of pollution in many parts, natic SO_2 recorders were set up by the national the prefectural agencies to determine the con- rations, frequency, and the duration of atmo- ric SO_2 exposures. The number of measuring ions had increased from the beginning at the rategic locations in 1965 to as many as 1473 ions in 1979, forming an extensive sampling em for SO_2 (The Japanese Environmental Agency 1979).

The analysis of air provides a framework of knowledge, and a foundation for developing air quality management strategies, and for prompting the enactment of the Clean Air Act in 1967, and its amendments made in 1970.

Figure 1. Mean value of annual concentrations at 15 strategic locations.

Figure 1 shows annual changes in average concentrations of SO_2 at 15 strategic locations between 1965 and 1977, the concentration increased until 1967, and then declined gradually. The decline has proved the continuing effectiveness of regulation of air pollution sources by the national and the prefectural governments based on the act.

During the summers in the middle of 1960's, the worst average concentrations of SO_2 were experienced. In this period, an unrecorded needle blight of Japanese red pine, Pinus densiflora, occurred throughout the normal range of that species, predominantly in central Japan. Up to that time the disease had been little known and of little concern to forest pathologists. A specific fungus dominantly found on blighted needles was investigated by Kobayashi (1967), and he identified it as Rhizosphaera kalkhoffii Bubák which had been known as a causal fungus of a needle blight of spruce and fir in northern Europe and North America.

The results of inoculation experiments to Japanese red pine seedlings proved that the pathogenicity of the causal fungus was considerably weak for pines, and the disease would scarcely occur if pines grew under normal conditions (Tanaka and Chiba 1971). The unusual incidence of the disease occurring in the early summer of 1965 might be related to abnormal weather conditions--extremely little rain fell in early spring followed by heavy rain in May (Chiba and Tanaka 1968). Although the disease has not occurred so widely as in 1965, **severe damage has been observed in the vicinity of ore smelters or industrial areas. In addition,** Japanese red pine is highly sensitive to SO_2 (Inoue 1973), and the distinction between the needle blight symptoms caused by the disease and those caused by SO_2 is exceedingly difficult (Tanaka 1975, Tanita 1976). Therefore exhaustive experiments were conducted to examine the relationship of SO_2 with disease development.

A total of 163 two-year-old seedlings of Japanese red pine were exposed to 2.0 ppm SO_2 for 1,2,3, and 4 hours in a fumigation chamber before or after inoculation in the middle of July, with a water suspension of conidia of the fungus produced on PDA plates.

Damage was more severe in the treatment combining the fumigation with inoculation, especially inoculation before fumigation, compared with those in the treatment of fumigation without inoculation. Numerous pycnidia of the fungus were produced in large lesions on needles treated by fumigation after inoculation as well as fumigation for longer duration before inoculation, no obvious change in the appearance of needles was detected on the seedlings inoculated with the fungus without fumigation. Symptoms produced on the SO_2 treated needles, namely, large lesions with numerous pycnidia, were identical to symptoms of the needle blight occurring in the field (Chiba and Tanaka 1968).

Most pine seedlings displayed acute symptoms of injury following exposure to 2.0 ppm SO_2 for 2 hours. The SO_2 concentration used in this study was several times higher than that found in the ambient air. It was necessary to elucidate the relationship between SO_2 and disease development at lower concentrations because such conditions are frequently encountered in rural and forest regions. Therefore, three-year- old seedlings of Japanese red pine were exposed for 2 weeks in chambers to 0.2 ppm SO_2, the level of SO_2 is likely to be found in the ambient air (Tanaka 1976a).

In this experiment, special emphasis was placed on the effect of SO_2 fumigation after inoculation in comparison with the treatment before inoculation. **The treated needles with SO_2 fumigation after inoculation were more severely affected by the fungus,** compared with those fumigated by SO_2 gas before inoculation. This result is consistent with findings of the 2.0 ppm SO_2 fumigation (Chiba and Tanaka 1968). SO_2 injury appeared to facilitate the spread and reproduction of the fungus within tissues of needles rather than to increase the initial rate of infection by the fungus.

To further examine these findings from artificial SO_2 exposure of seedlings in chambers, field experiments were planned and conducted during the summers of 1972 and 1973 by using a transplanting method (Tanaka et al. 1974a) and a filtered air method (Tanaka et al. 1974b) in Hiroshima Prefecture. In the transplanting study, two experimental plots were established. One was in Fukuyama city close to a large steel refinery. Especially in this area, distinct SO_2 damage markings on the needles of Japanese red pine were visible. The other was in a rural area in Miyoshi city. It was located about 60 km north of a highly industrialized area along the Seto Inland Sea including Fukuyama city. In the rural area, the disease caused by <u>Rhizosphaera</u> <u>kalkhoffii</u> had not been noted in recent years. A total of 900 potted seedlings of Japanese red pine used in the transplanting study were cultivated previously in the nurseries in the rural area in Miyoshi city. Seedlings were divid into 12 groups as shown in figure 2 according to the combination of transplanting and inoculation.

SO_2 concentrations of both areas were determin by means of the lead peroxide method. Needles we analyzed for sulfate-S and for total-S dry basis in order to determine the accumulation of sulfur in the needles. Foliar symptoms were rated from 0 to 5, according to the degree of injury,and the average of these individual indexes provides the disease severity for each group.

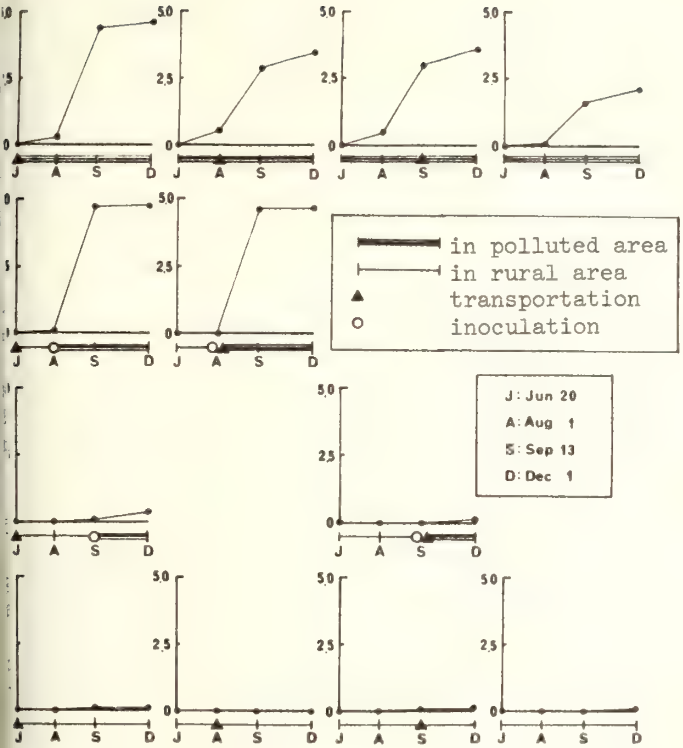
After being transported from the rural area to the industrialized area, several seedlings exhibited typical symptoms and signs of the disease, while others remaining in the rural area displaye no evidence of injury, even though they received the conidial spraying of the causal fungus (figur 2).

In the experiment using a filtered air method, an experimental plot was established in an area in Mihara city close to a powdered-coal-burning power plant. In this area, a large number of nee dle blighted Japanese red pines were found, and they displayed gradual reduction in shoot and woo growth. The previous year's annual mean content of sulfur compounds in the air was 1.04 mg SO_3/1 cm^2 PbO_2 per day.

Plants were grown in plastic covered chambers One chamber (2x4x2 m) was equipped with carbon filters and blowers, and the control or ambient air chamber was provided with blowers. The air pass through each chamber at a rate of about one air change / min. SO_2 concentrations of the ambient air were determined by means of an automatic recorder, and SO_2 concentrations in chambers were measured by the lead peroxide method.

The experimental design was similar to the tr planting experiment in Fukuyama and Miyoshi, tha is, a total of 300 seedlings were divided into 1 groups according to the combination of exposure SO_2 and inoculation of the causal fungus, then s lings were placed in chambers to determine wheth some protection from infection could be obtaine when the air drawn into the chamber was filtere There was a large reduction in the severity of t disease in the filtered air compared with that o the disease in the ambient air. These findings field studies furnished the evidence that SO_2 in the air was responsible for the development of t disease. The sulfur content especially sulfate- in the needles of the trees exposed to SO_2 was s nificantly greater than that of untreated needl both in the transplanting and the filtered-air e periments.

An increasing in disease severity may be exp when air pollutants weaken trees, making them m susceptible to infection by weak parasites, or duced vigor to a degree that plants become pred posed to attack by facultative parasites, such <u>Rhizosphaera</u> <u>kalkhoffii</u>, and <u>Botrytis</u> <u>cinerea</u> P (Manning et al. 1970). Conversely, Linzon (195



igure 2. Effect of SO_2 on the development of eedle blight of pine caused by Rhizosphaera alkhoffii

d that smelter emissions decreased the inci- e of Cronartium ribicola C.J.Fis.,and there are tional reports that aggressive or obligate para- s, such as Microsphaera alphitoides Griff. et l.(Köch 1935), and Melampsorella cerastii Wint, dermium coloradense Arth. et Kern, and some ies of Melampsora and Gymnosporangium (Scheffer Hedgcock 1955) were less abundant in areas ad- nt to smelter zones or to industrialized areas. found a similar case in Tokyo that a close re- onship existed between the increase of distance the metropolitan area and the increase of the ence of willow rust disease caused by psora coleosporioides Dietel and a leaf rust se of Styrax japonicum Sieb. et Zucc. caused cciniastrum styracinum Hirat. The complex of ollutants was brought about by urbanization ndustrialization, typical of the mixture of tants occurring in and around Tokyo, but SO_2 onsidered to be principally responsible for ing the abundance of these fungi.

OXIDANTS MAINLY OZONE (O_3)

ginning in the 1970's, changes from solid to d and gas fuels, and especially increasing use tor vehicles, have caused a reduction of the ype of urban pollution and an increase of e" pollution.

sonal communication from S. Ito, University kyo, January 15, 1980.

On July 18, 1970, Zelkova serrata trees in a yard of a senior high school located in Suginami Ward in Tokyo showed unusual shedding of their leaves, and strawberry leaves showed white spots clearly indicating the effects of oxidants. In addition to the damage to plants, 45 students of the school were hospitalized for treatment of irritated eyes, sore throats and difficulty in breathing. From this evidence, the Metropolitan Government issued the statement that the damage to humans and vegetation was caused by photochemical air pollution (The Tokyo Metropolitan Government 1971), and this was thought to be the first episode of "Los Angeles type smog" in Japan. But as a result of later investigations it was found that there were differences between Tokyo and Los Angeles air pollution, since SO_2 concentration and humidity in Tokyo were much higher than in Los Angeles; furthermore, it was confirmed that there was formation of sulfuric acid in the air (The Tokyo Metropolitan Government 1971). These findings suggest that the complex of photochemical oxidants and sulfuric acid might exert a far greater influence on humans and vegetation than any other alone at that time.

In the latter half of 1970's, with continuous increasing industrialization and transportation, every major city in Japan has experienced an increasing in photochemical oxidants even though there was a slow but steady decline in the concentration of SO_2 in the ambient air (figure 1).

Photochemical oxidants, mainly ozone (O_3),continue to cause the defoliation of broad leaf trees. Especially, in the Kanto district, at the center of Tokyo, unusual defoliation of Zelkova serrata still continues, since it is sensitive to both SO_2 (Inoue 1973) and O_3 (Kadota and Ohta 1972). While, in the Kansai district,at the center of Osaka, there is a high incidence of defoliation of poplar trees in the early summer in the parks, the gardens or the yards of schools throughout the district.

In addition to the measuring system of SO_2 throughout the country, a number of automatic oxidant recorders were also set up by the national and the prefectural agencies, but there is still a shortage of satisfactory apparatus for monitoring the low ambient concentrations. To make up for the shortage of an instrumented system, plants have been used extensively as bioindicators of air pollution. The use of bioindicators has long been accepted, since damage to green plants is usually one of the first signs that air pollution is becoming a serious problem (Berry 1964); their usefulness in this capacity is based primarily on the sensitivity of selected plant species and varieties for specific pollutants (Heck 1966).

Many clones, species and varieties of poplars were selected as bioindicators because of their high sensitivity to oxidants and their wide distribution, especially in the Kansai district. They also have enourmous advantages in that they are fast growing, easy to propagate vegetatively by

cuttings, and are uniformely sensitive to oxidant injury.

Despite these advantages, poplars are frequently plagued by various kinds of insects and diseases that degrade the usefulness of poplar clones as pollution indicators. For example, interpretation of the response to oxidants is made difficult by leaf diseases caused by Marssonina brunnea (Ell.et Ev.) Magnus, Septotinia podophyllina Whetz. and Melampsora larici-poplulina Kleb. A reliable guide to distinguish among symptoms caused by air pollutants, insects, and diseases has been developed and published (Tanaka 1975). The defoliation caused by Marssonina brunnea is one of the most serious diseases. It occurs wherever poplars grow, and is not restricted to urban regions, but frequently occurs with severity in urban areas. The disease develops tiny spots with light margins about 1 mm in diameter over the entire surface of the leaf. These superficial spots are not so difficult to distinguish from the symptoms caused by ozone by plant pathologists with a trained eye, but many people who want to use poplars as indicators are confused with the similar symptoms produced by ozone and the disease (Tanaka 1975). In addition, the disease causes premature lower leaf abscission,and the defoliation progresses upward toward the tips of the shoots from the late spring through the summer months. The unsightly appearance of affected trees discourages poplars' use as indicators of oxidants.

A number of investigators suspected that abscission was not due directly to the pathogen but resulted instead from increased rates of ethylene production from the infected plants (Abeles 1973), further, ozone-induced abscission of leaves of varying maturity was closely correlated with rates of ethylene production (Abeles 1973). From these reasons, Tanaka (1976b) hypothesized that increase rates of ethylene production caused by the synergistic effects of the infection of the fungus and ozone was responsible for the incidence of the dis ease in the urban area.

Fortunately, there is striking variability in susceptibility of poplar clones to the fungus and ozone. Clones were selected that are sensitive t ozone and resistant to the disease. The selectio offers one of the best means of increasing the us bility of poplar clones as ozone indicators (Tana 1977a). Table 1 presents the relationship betwee ozone sensitivity and disease resistance of popla clones (Tanaka 1977a). The data of resistance of poplar clones to the disease are based on the thr years' observation made in Osaka using 38 clones young rooted cuttings (Tanaka 1977a), and the dat of ozone sensitivity of them are based on the results from the exposure experiments with 0.15 ppm ozone for 40 hours in chambers conducted by Enoki (1977).

Populus maximowiczii cv. OJ 115 and cv. OJP 1, P.maximowiczii x P.trichocarpa cv. OP 41, P.maxim wiczii x P.nigra plantierens cv.OP 52, and P.nig italica x P.maximowiczii cv.Kamabuchi are promis clones for ozone indicators because they are sens tive to ozone and resistant to the disease (tabl

Yambe (1978) also attempted to find a possibl usefulness of the change of microbial flora on b boo leaves as indicators for air pollution. He found that Puccinia kusanoi Dietel and epiphytic bacteria on the leaf surfaces of bamboo decrease sharply in number in the urbanized and industria ized areas.

Table 1. Relationship between clonal susceptibility of poplars to O_3 and to Marssonina brunnea.

Susceptibility to O_3	Susceptibility to Marssonina brunnea: Highly resistant (RR)	Resistant (R)	Moderately resistant (MR)	Susceptible (S)	Highly susceptible (SS)
Highly resistant (RR)			NR 6 OP 29	NR 84	
Resistant (R)			NR 2, OP 26, Serotina	NR 19, NR 32	I 45/51
Moderately resistant (MR)		OP 285		L 230, L 293, LK 83, LW 42, NR 24B	
Susceptible(S)	OP 52	OP 1, OP 20		Gerlica I 154, I 214	I 262
Highly susceptible (SS)	I 72/51, Kamabuchi, OJ 115, OJP 1, OJP 2, OJP 3, OJP 4, OJP 5, OP 41				I 77/51, I 488

OTHER POLLUTANTS

In addition to SO_2 and oxidants, significant and etimes devastating effects of other air pollu-ts have long been recognized in Japan. Fluoride pounds have a long history as pollutants in the inity of ceramic industry, and more recently, nt injury resulted from fluorides has gradually reased because of the expansion of industries h as aluminum refineries and fertilizer manu-tures (Matuura and Kokubu 1972). Chlorine (Ta-a 1977b), ethylene, acidic dust from stacks, and aline dust from cement kilns (Inoue 1972a and 2b) have also been recognized as agents of dam- to vegetation, but the damaged areas are rela-ely restricted because most of them are emitted n point sources or by accidental spills.

The interaction of these minor pollutants with gi and bacteria has received only minor atten-n, but Inoue (1972a and 1972b) found that the ber of fruiting bodies of Tricholoma matsutake ger was significantly reduced in the heavily ed forests in the vicinity of cement works com-d to less severely dusted or non-dusted por-s of forests. According to the results of -dusted experiments,he concluded that the alka- solution from the dust severely decreased the ation of the fruiting bodies, and reduced the lopment of the fungus colonies.

CONCLUSIONS

The interaction of pollutants with parasitic and hytic microorganisms has received limited at-tion in Japan. The existing reports are only ciated with trees and bamboos and no report annual plants was found in a search of avail- literature.

ome pollutants are directly toxic to microor-isms on the leaf surface. They might possibly r their growth or reproduction, and change the ation and community composition of microorgan- on the host plants, since the sensitive spe- to air pollutants would be gradually replaced re tolerant species (Treshow 1968). Especial-ggressive or obligate parasites such as Cerco- sequoiae (Kaburagi 1930), Pucciniastrum sty-um and Melampsora coleosporioides (Ito[1]), and nia kusanoi (Yambe 1978) are less abundant in ted areas, and the disease severity they induce arply reduced.

 the other hand, in forest stands under influ- of industrial and urban air pollution, some r pathogens counted by pathologists in the of so-called 'facultative parasite' are of er importance because air pollutants injure tissue and predispose trees to attack by tative parasites. A close correlation has found between SO_2 in the air and a high inci- of needle blight of pine caused by a weak parasite, Rhizosphaera kalkhoffii (Chiba and Tanaka 1968).

Although plant injury caused by specific pollutants such as SO_2, O_3, and fluorides has gradually been abated by engineering improvements or by-products recovery, chronic injury caused by a complex of urban air pollutants has assumed additional importance as urbanization and the use of motor vehicles have increased.

Injury to green plants is usually one of the **first signs that air pollution is becoming a serious** problem, and severity of specific diseases in polluted areas must be regarded as an additional expression of unbalanced natural conditions. These specific diseases and the change of composition of leaf surface microorganisms provide aids for monitoring air pollutants, especially if they are sensitive to very low concentration of air pollutants. These diseases and microorganisms should be considered a useful supplement to the more expensive techniques and instruments used for the identification of chronic air pollutant effects.

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[1] **Personal communication from S. Ito, University Tokyo, January 15, 1980.**

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Sensitivity of Lichens to Air Pollution with an Emphasis on Oxidant Air Pollutants[1]

Thomas H. Nash III and Lorene L. Sigal[2]

Abstract: The hypothesis that lichens are sensitive indicators of air pollution is now well established for oxidants, sulfur dioxide, hydrogen fluoride and trace elements. From field studies differential sensitivity of different lichen species around pollution sources is evident. Laboratory studies with the particular air pollutant generally confirm the same degree of differential sensitivity.

LICHENS AND THEIR ECOLOGY

Lichens, which strictly speaking are called .ichenized fungi, are composite plants represent- .ng a symbiotic union of algae and fungi to form norphological entities unlike either component (Ahmadjian 1967, Hale 1967). Although a few :pecies survive in aquatic environments, most are 'ound in terrestrial habitats, occurring on soil, :ocks and as epiphytes on other plants. All ichens are perennial plants with life spans arying from a few decades to reportedly thousands f years (Weber and Andrews 1973). Essentially ll lichens are autotrophs because of the photo- ynthetic activity of the algae. Metabolic ctivity in general is limited to periods when the ichens are moist, a condition which varies in oncert with atmospheric moisture conditions as ichens have no roots by which moisture might be osorbed from the substrate. Thus lichens are rominent examples of poikilohydric plants Larcher 1973) which also include bryophytes and ome lower vascular plants, such as desert species : Selaginella and ferns. Because of moisture constraints on photosynthetic activity, primary productivity assignable to lichens is generally small compared to higher plants. Nevertheless lichens may be important in ecosystem functioning. For example, lichens are generally recognized as important pioneer plants of xeric successional sequences because of their role in biologically controlled weathering (Syers and Iskandar 1973). In addition, lichens are important in mineral cycling, not only because of their ability to alter precipitation chemistry (Lang and others 1976), but also from the ability of blue-green algae containing lichens to fix atmospheric nitrogen. Denison (1973) has estimated that lichens are responsible for 50 percent of the nitrogen fixed in the Douglas-fir forests of the Pacific Northwest.

Lichens are morphologically divided into 3 major growth forms: crustose, foliose and fruticose. Crustose species are generally small, tightly attached to (or imbedded in) their substrate and poorly differentiated. Foliose species are generally larger, loosely attached to their substrate and stratified into several distinct layers. In contrast to the basically 2-dimensional foliose species, fruticose species are strongly 3-dimensional and grow out from their substrate. Most fruticose species are also differentiated into distinct layers. Of these morphological forms fruticose species are generally considered to be the most sensitive to air pollution (Fenton 1964), a fact which may be related to the high surface-to-volume ratio of this form.

LICHENS IN RELATION TO AIR POLLUTION

Different species of lichens are well-known to

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be differentially sensitive to air pollution (Nash 1976). A few species actually grow better in urban environments where air pollution levels are high in contrast to their performance in rural areas. Most species, however, exhibit varying degrees of sensitivity to air pollution and some are more sensitive than higher plants. Thus by documenting variations in abundance and species richness of lichen communities, it is frequently possible to identify pollution sources and to document the magnitude of the air pollution problem. Patterns within lichen communities may be attributable to many environmental factors other than air pollution, of course, and consequently it is extremely important that studies be made within a multivariate context, including both pollution factors and non-pollution factors.

The fact that lichens are differentially sensitive to air pollution is based on a series of field observations and laboratory experiments extending back over the past 130 years. Grindon (1859) and Nylander (1867) noted that lichens were disappearing from city centers. Later Arnold (1892) documented that lichens transplanted from rural areas to the center of Munich were not able to survive. Subsequently this "city effect" has been reported for many cities in Europe and North America (Hawksworth 1971). By air pollution most workers of the 1800's generally meant coal soot and related particulates. However, over the past decades a number of invisible gases, such as sulfur dioxide and ozone, have been identified as the major causes of air pollutant injury to plants. Experiments with these air pollutants over the past two decades have also demonstrated differential sensitivity among different lichen species. In general, the sensitivity patterns demonstrated in the laboratory have remarkably corresponded to the patterns observed in the field around pollution sources. Perhaps the strongest evidence supporting the contention that lichens are sensitive to air pollution comes from studies documenting lichen recovery following pollution abatement. For example, Seaward (1976) has documented that Lecanora muralis fairly rapidly reinvaded an urban complex in southern England following amelioration of air pollution in the area.

In the following sections specific evidence related to various types of air pollutants will be reviewed.

Oxidant Air Pollutants

Oxidant air pollutants, including ozone and peroxyacetylnitrate (PAN), are a group of gases characteristic of the oxidizing atmospheres found in the Los Angeles type smog (Pitts and Finlayson 1975). Although the effects of these compounds have been studied extensively with higher plants (National Academy of Sciences 1977), relatively few studies have been conducted with lichens. Probably the only field study in which lichens have been shown to be sensitive to oxidants is that of Sigal and Nash (1980) for the southern Californian mountains. The study was centered i the San Bernardino Mountains, utilizing the site employed by the University of California (Rivers and Davis) ecosystem study of air pollutant effe in contrast to sites in a control region, Cuyama Rancho State Park in southern San Diego County. In addition, there was an excellent historical record of the lichens of the San Bernardinos bas on collections made by H. E. Hasse at the turn o the century. Of the 91 foliose and fruticose lichen species reported by Hasse (1913) in his lichen flora of southern California, only 34 species were found during three summers of stud throughout southern California. Thus there has been a significant reduction in the number of species present. To obtain quantitative data o lichen variation, both conifers (Abies concolor Pinus ponderosa, Pinus jeffreyi and Pseudotsuga macrocarpa) and California black oak (Quercus kelloggii) were sampled for lichen cover at breast height.

In the case of conifers Hasse (1913) reporte the presence of 16 foliose and fruticose liche species in the San Bernardino Mountains. In ou recent study (Sigal and Nash 1980) only 8 of these species were found in the San Bernardino Mountains and 4 of these were only present in vestigial quantities. In contrast, at sites t the north and to the south (Cuyamacas) 15 of t 16 species reported by Hasse were found. Thus n the San Bernardinos which lie adjacent to the s Angeles Basin, there has been a 50 percent dec ne in species richness of lichens on conifers. O the species which do occur in the San Bernardi s only two (Letharia vulpina and Hypogymnia ente- morpha) occur commonly. The latter species, although it is common, is definitely showing sgns of deterioration (Table 1) when randomly selec d thalli from the San Bernardinos are compared w h a similar set from the Cuyamacas. The San Ber nardino population has a much higher percentag

Table 1-- Morphological characteristics of re nt collections of Hypogymnia enteromorpha from t San Bernardinos and the Cuyamacas.

		Percent Bleaching			
Forest	n	un-bleached	slight-ly	moder-ately	bl ch
San Bernardinos	66	0	30	27	3
Cuyamacas	38	59	41	0	0

		Percent Convoluted			
Forest	n	uncon-voluted	slight-ly	moder-ately	conv-lute
San Bernardinos	66	0	3	53	44
Cuyamacas	38	38	47	15	[illegible]

of bleached and convoluted thalli. In additi n, there was a decrease of approximately 50 per nt in overall thallus dimensions in the San Ber rdi population and a decrease in fertility of 42

ɪrcent. Thus there are marked trends between the
ın Bernardinos and the Cuyamacas of reduced
ɪecies richness and species vitality in the form-
' area. Within the San Bernardinos themselves,
.gnificant variation exists. Below approximately
0 ppm-h oxidant dosage, cover of both Letharia
d Hypogymnia is normal in comparison with other
eas. At higher dosages of up to 285 ppm-h
chens are almost completely eliminated from
nifers.

Comparisons of trends of lichens occurring on
ack oak between the San Bernardinos and Cuyamacas
so indicated that a deterioration was occurring
the San Bernardinos, but the trends were not as
amatic as in the case of lichens occurring on
nifers. No direct comparison with the Hasse
terial was possible because Hasse did not note
e species of oak in his collections. From our
mpling 39 species of lichens were found on black
k in the Cuyamacas and 30 species in the San
rnardinos. Fourteen of the species found in the
yamacas were not found in the San Bernardinos
ereas three species were found exclusively in the San Bernardinos. Among the 20 species which occurred in common there was a general shift from high frequency in the Cuyamacas to relatively low frequency in the San Bernardinos. In the case of cover of the 6 most common species, no significant difference was observed between the two mountain ranges except for Collema nigrescens, the only nitrogen fixing lichen in the group, which was completely absent from the San Bernardinos. Further analysis revealed that Parmelia subolivacea, the most common lichen, was a successional species. Because older trees occurred in the Cuyamacas, a significantly higher value for this species in the Cuyamacas was predictable. Further evidence supporting the hypothesis that the dominant species was in fact responding to oxidants was obtained by running ordinations (principal component analysis) of the sites within the San Bernardinos and relating the observed variation in species composition to oxidant dose estimates and other environmental variables (fig. 1). An initial ordination (not shown) included all sites sampled within the San Bernardinos. It exhibited a small cluster of low cover sites which occurred at the

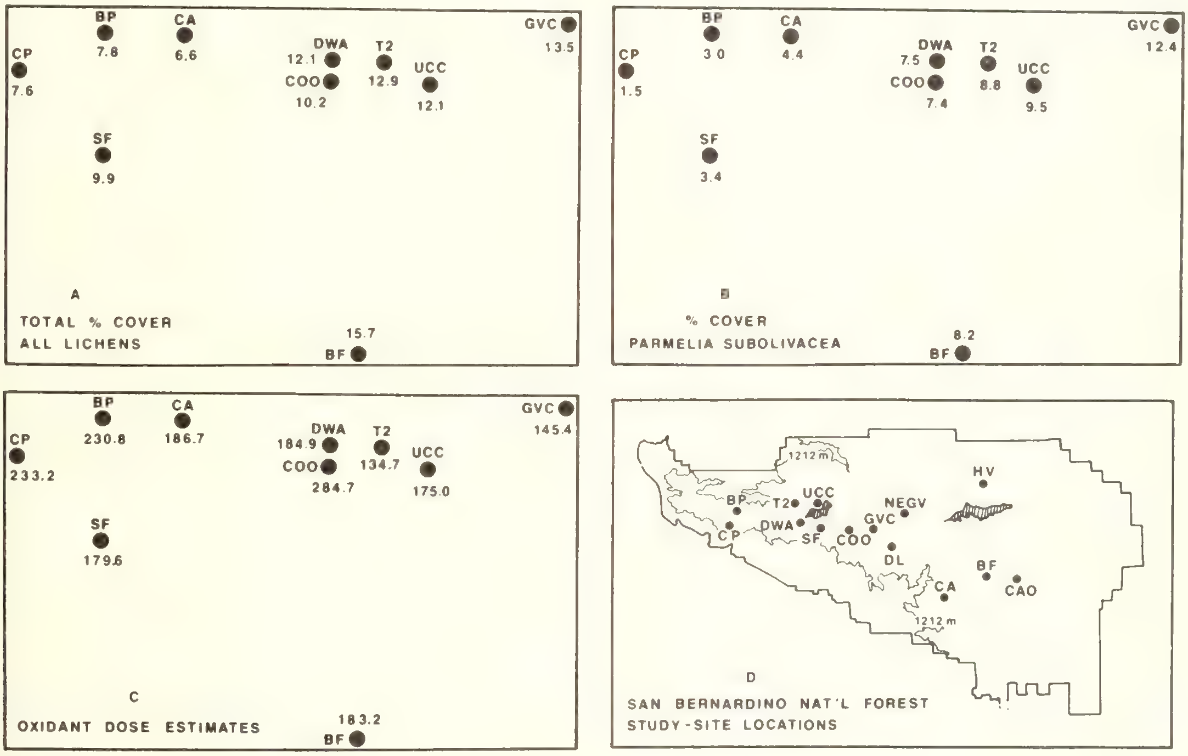

Fig. 1--Principal component analysis ordination of 10 sites in the San Bernardino Mountains using cover data for the 5 most important lichen species occurring on Quercus kelloggii. Eighty percent of the variation is explained by axis one (the abscissa). Figure 1A shows the positioning of the sites on the ordination plot with respect to total cover of all lichens; figure 1B, the same ordination but with cover values for Parmelia subolivacea; figure 1C, the same ordination, but with oxidant dose estimates (ppm-h); figure 1D, the geographic location of the sites within San Bernardino National Forest.

highest elevations where summer fog is infrequently observed. Consequently these sites and one other site on the desert side of the San Bernardinos were excluded from the subsequent analysis. The 10 sites plotted in figure 1 are thus homogeneous with respect to altitude and position along the Los Angeles side of the San Bernardinos (fig. 1D). In the subsequent ordination (fig. 1A, 1B and 1C), 80 percent of the variation is explained by axis 1 (the horizontal axis). From figures 1A and 1B it is clear that the primary source of variation is the percent cover of all lichens, which in turn corresponds closely to the percent cover of P. subolivacea. Furthermore, there is an inverse relationship between percent cover of P. subolivacea (fig. 1B) and oxidant dose estimate (1C). This inverse relationship was substantiated by running a Spearman rank correlation between the two variables. The test was significant with an alpha value of 0.007. For the other 4 species no relationship between oxidant dose estimates and cover values were found. Thus some species have been completely eliminated from the San Bernardinos, other species have probably declined in abundance and a few species are apparently unaffected.

Preliminary ozone fumigations have shown differential responses in photosynthesis reduction between Parmelia sulcata and Hypogymnia enteromorpha with the former species exhibiting greater sensitivity (Nash and Sigal 1979). The Parmelia, which grows on black oak, is absent from the San Bernardinos whereas the Hypogymnia is present, but is exhibiting signs of deterioration. For these species, at least, the pattern of sensitivity observed in the field and the laboratory are complementary. A similar pattern of response for the two species was observed after fumigations with PAN (Sigal and Taylor 1979). Further studies with both ozone and PAN should be run, but the current evidence strongly supports the assertion that oxidants are a major cause of the decline of the lichen flora in the San Bernardino Mountains.

Sulfur Dioxide

Sulfur dioxide is released into the atmosphere by combustion reactions involving products containing the ubiquitous element sulfur, such as coal and oil. It has long been recognized as a phytotoxic agent in general (Daines 1968). Lichens are well known to be sensitive to sulfur dioxide (Nieboer and others 1976). Most of the field studies in northern Europe and North America have involved sites where sulfur dioxide was a major factor (Hawksworth 1971). One of the classic studies by Rao and LeBlanc (1967) demonstrated a severe decline in lichen abundance along a 70+ km transect NNE of Wawa, Ontario where an iron sintering plant is present. Because there is essentially no human development in the affected region, air pollution, and particularly sulfur dioxide, is undoubtedly a major cause of the decline in the region's lichens. Other studies have shown that lichens accumulate sulfur (Olkkonen and Takala 1975, Laaksovirta and Olkkonen 1977) in situations where the presumed source of sulfur is sulfur dioxide. The gas readily dissolves in water forming a sulfite or bisulfite solution depending on the pH. As a c[illegible] sequence acidification of the substrate frequen[illegible] occurs, as has been shown in Stockholm where Sk[illegible] (1968) found that urban tree bark had a pH of m[illegible] than two units less than corresponding trees fr[illegible] the country-side. Acidification strongly affec[illegible] the ability of lichens to survive, in part beca[illegible] sulfur dioxide is much more toxic at lower pH's (Tuerk and Wirth 1975). Gilbert (1965 and 197[illegible] has clearly demonstrated the ability of lichens to penetrate into central Newcastle on basic su[illegible] strates when they are absent from acidic ones. In the laboratory studies, photosynthetic decli[illegible] in response to short term sulfur dioxide exposu[illegible] as low as 0.2 ppm have been demonstrated (Tuerk and others 1974). In aqueous experiments with reputedly lower concentrations, effects have a[illegible] been documented (Baddeley and others 1973, Puck[illegible] and others 1974). In addition to reduction of photosynthesis, bleaching of lichen thalli may occur due to phaeophytinisation of the chlorophylls (Nash 1973, Puckett and others 1973). [illegible] recently potassium efflux from lichens exposed [illegible] sulfur dioxide has been shown to be the most s[illegible]sitive criterion of response (Tomassini and ot[illegible] 1977). Alteration of membrane permeability ma[illegible] thus be an immediate response to sulfur dioxid[illegible] exposure. Subsequently it is suggested (Niebo[illegible] and other 1976, Puckett and others 1974) that interference in electron flow in photosystem I [illegible] II will occur and that proteins will be affect[illegible] through sulfur dioxide's ability to cleave disu[illegible]phide linkages. Thus there is very strong evi[illegible]dence from both field and laboratory studies t[illegible] lichens are sensitive to sulfur dioxide.

Hydrogen Fluoride

Hydrogen fluoride is extremely volatile an[illegible] released into the atmosphere during aluminum a[illegible] rare earth metal refining, fertilizer producti[illegible] and glass and ceramic manufacturing. Patterns [illegible] lichen decline are well demonstrated around a[illegible]num factories (Martin and Jacquard 1968, Gilb[illegible] 1971, LeBlanc and others 1972, Horntredt 1975[illegible] around a titanium plant (Nash 1971) and aroun[illegible] phosphate plant (Takala and others 1978). In these areas fluoride accumulation by the liche[illegible] has been demonstrated with decline in the lic[illegible] communities being associated with elevated fl[illegible]ride levels. Transplants of healthy lichens [illegible] the impoverished zones resulted in fluoride a[illegible]mulation and subsequent death of the transpla[illegible] Gilbert suggested that the critical fluoride [illegible] lay between 20 and 50 ppm and Nash independen[illegible] suggested that the value lay between 30 and 8[illegible] Schoenbeck (1969) found that his transplants [illegible] near a fluoride source, but that new transpla[illegible] survived well for several months following ce[illegible]tion of the fluoride emissions. In a laborat[illegible] study with exposure to approximately 5 ppb fl[illegible] over a 9-day period Nash (1971) found that li[illegible] accumulated 84-115 ppm fluoride in contrast t[illegible] control levels of 14-25 ppm and that the fumi[illegible] samples developed chlorotic and necrotic symp[illegible]

similar to the injury observed in the field trans-
plants. Thus fluoride as the probable cause of
the injury was confirmed.

Trace Elements

Lichens have a well demonstrated ability to ccumulate elements from dilute aqueous solutions Nieboer and others 1977), a fact probably related o their apparent dependence on atmospheric ources for mineral nutrition. As a consequence f this ability to retain elements, the study of race element concentrations in lichens is fre- uently useful in demonstrating "fallout" patterns f particulates and aerosols. For example, mercury s found in elevated concentrations near a chlor- lkali works in Finland (Lodenius and Laaksovirta 979); lead is elevated in lichens adjacent to ighways (Laaksovirta and other 1976, Lawrey and le 1979); and a number of elements are present high concentrations in cities, such as Tel Aviv arty and others 1977) and Sendai, Japan (Saeki d others 1977), near the nickel complex at dbury, Ontario (Tomassini and others 1976), near coal-fired power plant (Gough and Erdman 1977) d in coal mine ecosystems of Ohio (Lawrey and dolph 1975). In none of these cases is toxicity the accumulated elements demonstrated. Toler- ce to high concentrations of elements may occur the elements are relatively insoluble and are calized extracellularly. For example, Noeske d others (1970) showed that iron and copper re encrusted on the surface of lichens which ew on metal rich substrates in the Harz Moun- ins of Germany. Furthermore, Garty and others 979) have shown that particulates in Tel-Aviv e incorporated extracellularly within the chen thallus.

In contrast to the above studies "trace" ele- nts do occasionally occur in toxic concentra- ons. Lawrey and Hale (1979) have shown accumu- ion of approximately 1000 ppm lead in a lichen wing near an expressway in the vicinity of hington, D.C. They demonstrated that lead umulation is correlated with reduction in wth of the species, but they have neither onstrated experimentally that lead was the se of the reduced growth nor demonstrated that er factors associated with automobile emissions e unimportant. Probably the most convincing dy documenting trace element toxicity is that Nash (1975) around a zinc smelting complex in tern Pennsylvania. In the vicinity of the lting complex, lichen species richness was uced to 7 in contrast to the 77 species found a control area (Nash 1972). The zone of hen impoverishment extended for a distance of km W and 10 km E of the smelting complex g. 2). Although detectable and potentially ic levels of sulfur dioxide were found adja- t to the smelters, the distribution of vated levels of sulfur dioxide did not extend far as the lichen impoverishment zone extended. relative unimportance of sulfur dioxide was ther documented by the lack of acidification the bark of oak trees and by the fact that the

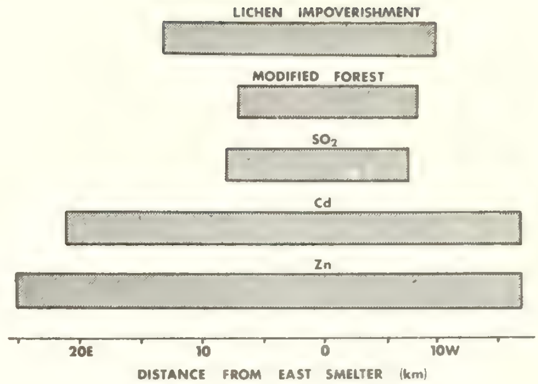

Fig. 2.--The distribution of the lichen-impoverished zone (Nash 1972) at Palmerton, Pennsylvania, in relation to the zones of modified forest (Jordan 1975), to detectable levels of ambient sulfur dioxide (Nash 1975), and to elevated levels of cadmium and zinc in surface soils (Buchauer 1973).

company had installed and subsequently continuously used an acid plant at the time that zinc sulfide ores were initially processed. In contrast, metal concentrations in the soil duff were as high as 135,000 ppm zinc and 1750 ppm cadmium at a site adjacent to the smelting complex (Buchauer 1973). The concentration of zinc and cadmium decreased exponentially with distance from the smelters until background concentrations were found at 20 to 25 km E and 16 km W of the smelters (fig. 2). Physiological studies demonstrated that zinc and cadmium were toxic to the lichens when concentrations reached 300-500 ppm in the thallus. Since zinc was present in concentrations 100 times that of cadmium and since zinc is approximately as toxic as cadmium, zinc was inferred to be the most important pollutant. At points beyond the lichen impoverishment zone zinc concentrations ranged from 20-200 ppm and cadmium from 1-30 ppm, where both sets of values were demonstrably non-toxic.

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Influence of Air Pollution on Population Dynamics of Forest Insects and on Tree Mortality[1]

Donald L. Dahlsten and David L. Rowney[2]

Abstract: Weakened trees are often predisposed to injury or death by insects, and in forest ecosystems particularly by bark beetles. In the San Bernardino National Forest the interaction between photochemical oxidant weakened ponderosa pine and the western pine beetle (WPB) was examined in detail. The major results from this study suggest that oxidant damaged trees attacked by WPB produce about the same total brood with lower initial attacks compared to healthier trees. This higher productivity trend is most evident in generation 1 trees. Generation 2 trees, both damaged and healthy, are under much greater moisture stress and produce much less WPB brood than generation 1 trees regardless of oxidant damage.

The implication of these results is that in stands with a higher proportion of damaged trees, a given population of WPB could kill more trees and increase at a greater rate than in a stand with a lower proportion of damaged trees. Simulation modelling with these results and other factors that affect ponderosa pine mortality should provide a basis for predicting long term effects of air pollution on the WPB population and pine mortality.

Most of the work on air pollution damage has focused on direct injury to the plant and Kozlowski (1980) gives a good review of the impact of air pollution on forest ecosystems. By comparison, little has been done on the indirect effects such as the predisposing of plants to insects or pathogens. Watt (1969) speculated on the effects of air pollution on population fluctuations of insects and Heagle (1973) reviewed the interaction between air pollutants and plant parasites. More recently the occurrence of diseases and insect pests of trees in air polluted regions of North America has been recorded (Dominik 1978).

There have been some studies on the direct effects of air pollution on insects. Feir (1978) studied the effects of air pollutants on insect growth and reproduction and Hillmann and Benton (1972) looked at the reactions of honey bees to sulfur dioxide.

Bromenshenk (1976, 1978) has studied the effects of coal-fired power plant emissions on a variety of insects. In another study, Gilbert (1971) looked at the indirect effects of air pollution on several bark inhabiting insects. Air pollution may be the cause for the scarcity of all orders of insects in New Jersey (Muller 1971).

The effects of insects in pine stands influenced by air pollution, particularly xylophagous insects, have been studied (Sierpinski 1972, 1977). In California on the San Bernardino Mountains, ponderosa pine shown to have advanced symptoms of oxidant injury were most frequently infested and killed by western pine beetle (Dendroctonus brevicomis), and mountain pine

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beetle (D. ponderosae) (Stark et al., 1968). The purpose of this study was to look a little closer at the interaction between the western pine beetle and oxidant affected ponderosa pine, to see what effect diseased trees would have on the dynamics of bark beetle populations and to look for differences between beetle population parameters in diseased and healthy ponderosa pine.

MATERIALS AND METHODS

Field Procedures

Beginning about the first week in July, the San Bernardino mountain areas with substantial ponderosa pine stands were searched for first generation western pine beetle attacked trees. These areas are generally on the southern side of the mountains at about 1500-1800 m elevation, and are areas where high oxidant air pollution levels occur. Second generation trees were located in mid-August to mid-September, depending on the timing of the first generation. Trees under attack were detected by pitch tubes or frass in bark crevices. Attacked trees were checked with an axe at the base to see which species were attacking and to check the stage. Trees with mixed brood (D. ponderosae and D. brevicomis) and trees with strip attacks (one side only) were relatively uncommon and were not selected for this study. Trees with Ips spp. in the tops were selected, but sampling for western pine beetle was stopped at the base of infestation of the Ips. Each suitable tree located was used in the study until the required number were found (12 per generation in 1973 and 1974, 6 per generation in 1975 and 1976). In the time period allowed for sampling the initial WPB stages there was no practical way to locate all the attacked trees in the area and then pick a random subsample for the study.

Sampling

Prior to sampling, the major tree characteristics were recorded: location, height, DBH, height of first green branch, and estimated tree damage due to air pollution. The air pollution damage was rated by rating upper and lower crown needle retention, needle condition, needle length, and branch mortality. Needle condition and retention were difficult to rate on the sample trees because in many cases, fading and needle loss due to the bark beetle attacks had begun. For 1973 only one needle length rating was made for the entire tree, so the needle length rating for the other years was combined to be consistent in the analysis (in nearly all cases the upper and lower crown needle length was the same).

Samples for all procedures except where noted later were taken at 1.5 meter intervals over the length of the western pine beetle infestation. Two 88 cm^2 discs taken on opposite sides of the tree at 1.5 meter intervals gave the desired level of precision.

The samples were taken from the tree using a modified portable 4.5 kg gas powered drill (Drilgin®, Precision Multiple Control, Ridgewood, New Jersey). A standard circular hole saw with an 11 cm diameter blade was used in the chuck of the drill. This saw cuts an area of approximately 88 cm^2.

At each sample height the circumference was measured, then the two discs were cut. With the egg discs it was desirable to take a portion of the xylem with each disc to protect the galleries. After a disc was removed it was examined by the climber for insects, which were identified and called down to the notetaker.

During the last larval sample emergence cartons were placed on the trees at each sample height. These cartons were not removed until well after brood emergence.

Laboratory Procedures

Once the samples had been returned to Berkeley, they were placed in cool storage until analyzed. X-rayed samples were placed into rearing immediately after the radiographs were taken. Basically there were four laboratory analysis procedures for sample discs.

Egg Disc Analysis

To determine egg mortality discs were taken at 3.0 meter intervals approximately two to three weeks after the mass attack period. Sampling at every 3.0 m interval gave 4 or more heights for each tree. Egg discs were taken only once, at the time of the first larval sample. This avoids an additional climbing of the sample tree, assures that maximum egg hatch has occurred and mortality can still be determined.

If xylem tissues still remained on the disc it was carefully removed so that the galleries in the phloem tissue were not disturbed. Gallery length was measured with a metric map reader and all attacks were recorded. Each disc was then examined with a dissection scope (10-20x) along the length of all the adult galleries. Each egg niche was evaluated as empty or as containing a viable egg or nonviable egg in addition to recording larval eclosion. The difference between the total number of egg niches recorded and the total number of larvae hatched was calculated as egg mortality.

X-ray Analysis

The first samples to be x-rayed were taken concurrently with the egg discs (egg discs are destroyed during analysis so they can not be placed into rearing). For generation one, an additional x-ray sample was taken late in the brood development period, usually in mid to late July. For the second generation, x-ray samples were removed on two later occasions: once in mid-September to October to check for early emergence of brood and

adult re-emergence, and finally in the following spring (March to April) after brood development was nearly complete, but before spring emergence.

The discs to be x-rayed were taken from cold storage as soon as possible and removed from the plastic bags. The average bark thickness of each disc was measured with a metric caliper and the percentage woodpeckering on each disc was recorded. The two 88 cm^2 discs from each height were placed on one sheet of 8" x 10" Industrial Kodak® AA-2 film and exposed with a Picker® radiograph machine. The samples were then rebagged and transported to a large storage shed for rearing (see below).

X-rays were interpreted for western pine beetle, live and dead parent adults, brood adults, pupae, and larvae, parasitoids, predators and miscellaneous. The miscellaneous category included buprestid and cerambycid larvae, weevils, _Ips_, and unknowns, of which there were many judging from the rearing of these discs. A light table was used for interpretation and all inclusions were marked with a grease pencil by the interpreter, counted and then erased. A second interpreter then repeated the process, thereby reducing error and bias. The x-rays from each tree were then stored in envelopes as a permanent record.

Laboratory Rearing

Each x-rayed disc was placed in a 1/2 gallon ice cream carton with a small 2 or 3 dram glass vial pushed through the lid. Since the insects in the discs are positively phototropic at least in the adult stage, and since very few beetles or other insects bore through the sides of the cartons, this was a suitable rearing procedure. The cartons were stored in racks in a large unheated warehouse where Berkeley's mild, cool climate provided an ideal rearing environment.

The emerging insects were collected from the vials three to five times per week. Most of the specimens could be identified with a 10x hand lens and then recorded on a data sheet by collection date. Only the parasitoids and the western pine beetle were sexed. All specimens have been identified by taxonomic experts and specimens are sent for verification regularly; the collection is updated as necessary. Approximately [3]0 different insects were recorded. In this paper, only WPB, 4 predators (_Enoclerus lecontei_, _[Te]mnochila chlorodia_, _Aulonium longum_, _Medetera [al]drichii_) and 4 parasites (_Roptrocerus xylophagorum_, _Dinotiscus burkei_, _Eurytoma conica_, _[H]eloides_ sp. nr. _brunneri_) are considered.

Sample discs were kept in rearing for nine months and at the end of this period the cartons were examined for any remaining insects; the discs were then discarded. The gallery length and number of attacks were recorded for each disc prior to discarding. Attack holes can be distinguished from emergence holes as they are oblique to the surface of the bark and often have pitch as a remnant of a pitch tube.

Field Emergence Cartons

As an additional check on emergence, a procedure for rearing _in situ_ on the sample trees was also used.

One quart squat ice cream cartons that cover 88 cm^2 of bark were painted silver on the outside and prepared with a screened ventilation hole. Stikem Special® was placed on the inside of the cartons to discourage insects from boring out or from going back into the bark. A groove was cut in the bark with the sampling saw into which the lip of the carton was placed; a nail was driven through the bottom of the carton and into the tree to increase stability.

The cartons were placed on the tree at the time the last x-ray or brood sample was taken (to coincide with the pupal and/or callow adult stages of the brood) and were left in place for up to three months, until well after beetle emergence and the collection of all associated insects had taken place. The second generation cartons were not placed on the tree until early spring since cartons do not weather well and therefore cannot be left on the trees for four to six months over winter. The cartons were split open and examined under the microscope and then discarded. The same insects that were recorded for laboratory rearing were recorded for the sticky emergence carton.

RESULTS AND DISCUSSION

Attacked tree characteristics and variation by year and generation:

The tree heights of the 71 attacked trees sampled over the four year period varied from 13 to 44 meters, but most trees were in the 20-30 meter range (Fig. 1). Tree DBH, stem volume, and infested bark area varied more widely, but exhibited no significant trends with regard to year and generation. Western pine beetle attack and emergence density, however, both showed significant differences ($P < .05$) by generation. Year differences were not significant for these variables except for a lower attack density for generation one trees of 1976 compared to the generation one trees of the other three years.

Effect of tree oxidant damage on beetle population:

In order to determine if damage to the sample trees had an effect on the western pine beetle populations, the individual components of the damage score were analyzed with respect to beetle attack density. Each individual component of the score can be regarded as an interval level variable, so multiple regression techniques were used to determine their relationship to attack density. The technique used was a full screen analysis

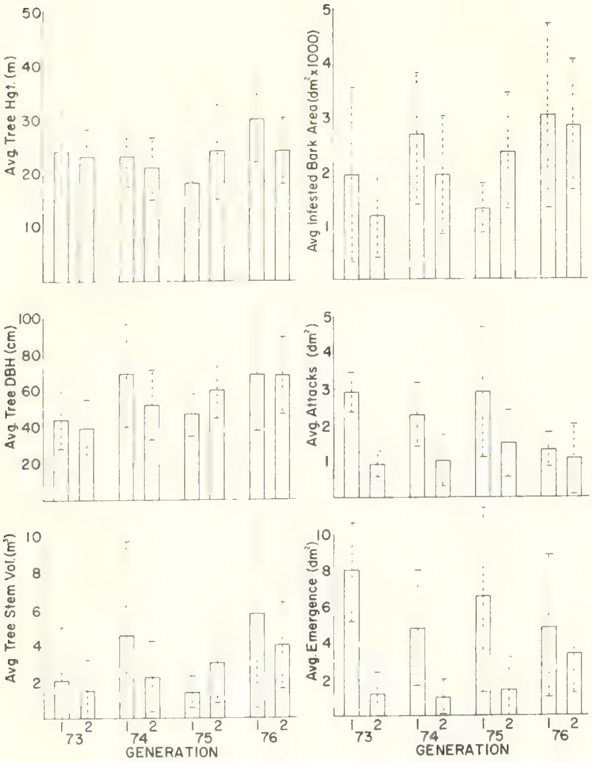

Fig. 1.
Western pine beetle attacked tree characteristics, attack density and emergence density by generation and year for 71 ponderosa pines in the San Bernardino National Forest, California. (dashed lines = mean ± one standard deviation)

which calculated R^2 values for all possible linear combinations of the score components, year, and beetle generation for the attack density dependent variable. The results of this analysis indicated that only the needle length (NL) component (upper and lower crown combined) of the score was significant ($P < .05$) along with beetle generation. The effect of any other components was insignificant when added to the equation containing NL and generation. Some of the other components which have been significant in other studies - needle retention and needle condition - probably were unreliable for these trees as they were examined in a partly faded condition some weeks after being mass attacked by bark beetles. In subsequent analyses the needle length (NL) was used to distinguish between trees highly affected by air pollution (NL=0) and less affected trees (NL=1). Table 1 gives mean values of the attack density and other western pine beetle variables for each generation and needle length category. In our sample of trees significantly fewer short NL trees were found in generation one (7 of 36) compared to generation two (16 of 35), but due to the practical limitations of our sample selection procedure, it is uncertain whether this difference holds true for the entire population of attacked trees.

The attack density was significantly higher for long NL trees compared to short NL trees for both generations, while generation two trees had lower attack densities than generation one regardless of NL.

Most other generation one beetle variables were not significantly different between short and long NL trees, except for eggs per attack and emerged brood per attack (Table 1). This probably indicates that the attacking beetles for generation one were more productive when the trees had lower attack density and less competition within the trees. The short NL generation 1 trees, with lower attack densities, had essentially equal numbers of eggs and emerging brood compared to the long NL trees.

The trend toward high productivity in the lower attack density, short NL trees for generation 1 was not evident for generation 2. The beetles in the short NL trees had essentially the same eggs/attack and emerged brood/attack as those in long NL trees (Table 1). Total eggs, hatched eggs, and late larval densities were all significantly lower in the lower attack density, short NL trees. Mortality proportions for each life stage sampled seemed relatively independent of NL although they were higher in generation 2 compared to generation 1.

Table 1--Western pine beetle variable means by ge eration and tree air pollution injury(needle leng

	Generation 1		Generation 2	
Injury:	Short NL	Long NL	Short NL	Long NL
No. of trees	7	29	16	19
Attacks/DM^2	1.69*	2.65	0.72*	1.34
Gallery length/DM^2	65.8	72.8	37.1	43.4
Total eggs/DM^2	71.6	67.8	39.7*	60.1
Eggs/attack	62.3*	30.1	64.7	57.9
Hatched eggs/DM^2 (1st instar larvae/DM^2)	58.3	55.1	30.4*	44.5
Egg mortality	0.20	0.19	0.25	0.29
Late larvae/DM^2	12.0	17.2	2.37*	4.84
Larval mortality-- early to late larvae (LM)	0.78	0.69	0.91	0.85
Emerged WPB (REAR)/DM^2	6.08	6.16	1.24	1.67
Mortality-late larvae to emergence (REAR) (BM)	0.42	0.58	0.53	0.71
Mortality-eggs to emergence (REAR)	0.91	0.91	0.97	0.97
Emerged brood per attack	4.12*	2.53	2.53	1.93

*Significant differences between NL classes, $P < .05$.

Needle length was also used to compare differ-
ices in predator and parasite densities for each
ineration (Table 2). Predators included the
common species: Enoclerus lecontei, Temnochila
lorodia, Aulonium longum, and Medetera
drichii. Parasites included Roptrocerus xylo-
agorum, Dinotiscus burkei, Eurytoma conica and
eloides sp. nr. brunneri. For generation 1,
ly emerged (REAR) predators/dm^2 were signifi-
ntly higher for the long NL trees. For genera-
ion 2, initial parasitized larvae/dm^2 were higher
r short NL trees, but late parasitized larvae/
^{2} were higher for long NL trees.
much larger increase
numbers of
rasitized larvae occurred for the gen. 2, long
trees. Increased woodpeckering, along with a
gher final larval density for the long NL trees
y explain the increased numbers of parasitized
rvae. A similar proportion (about 1%) of
itial larvae were parasitized in both cases.

ole 2--WPB predator and parasite means by gen-
ation and tree air pollution injury class
(eedle length).

	Generation 1		Generation 2	
Injury:	Short NL	Long NL	Short NL	Long NL
N trees	7	29	16	19
I tial pred./DM^2	0.962	1.910	0.53	0.30
I tial para- itized lar./DM^2	0.20	0.36	0.18*	0.08
L e predators/DM^2	1.83	2.75	0.80	0.84
L e parasitized arvae/DM^2	0.56	0.61	0.26*	0.48
E rged (REAR) redators/DM^2	0.73*	1.50	0.25	0.27
E r. (REAR) para/DM^2	0.48	0.42	0.22	0.28
% rea samples wood- eckered	0.1%	0.8%	7.0%	11.0%

*Significant difference between means of smog
i ury classes, $P < .05$.

T le 3--Ozone effects table: western pine
b tle in ponderosa pine.

O ne d e (	Tree needle length	Beetles into trees/ dm^2 (2)	Beetles out of trees/ dm^2 (3)	Total beetles (4)	Beetle caused tree mort. rate (4)
lo	long	4.0	3.9	constant or de- creasing	constant or de- creasing
hi h	short	2.4	3.7	increasing	increasing

No es:
(1 Effect depends on individual tree character- istics.
(2 Based on both generations combined and multi- plying female adult attacks by two to account for males.
(3 Based on both generations combined.
(4 Assuming constant no. of damaged pines/stand.

The consequences of bark beetle activity in an area are summarized in Table 3 and show that attack rates are lower on oxidant affected trees, but the output of brood is essentially the same in healthy and diseased trees. Bark beetles, assuming no direct deleterious effects of air pollution, should increase in areas with high ozone damage and tree mortality will also increase in these areas. The possible interactions of air pollution, ponderosa pine, and western pine beetle and the effects on forest succession are shown in Table 4.

Table 4--Interaction table: air pollution, ponderosa pine, and western pine beetle.

	Causes a change in		
	WPB pop. level	Ponderosa pine mortal- ity caused by WPB	Forest succes- sion
An increase in:			
air pollution	+	+	+
soil water	?	?	?
foliar injury	++	+	+
soil nutrients	?	?	?
mature tree growth	?	?	?
root disease	+	+	+
forest succession	-	-	0
WPB pop. level	0	++	+
pine mort. caused by WPB	?	0	+

Key:
0 = unrelated or not possible
\+ = moderate increase
++ = large increase
\- = a large decrease
? = unknown, needs more investigation

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Air Pollutants and Their Effects on Wildlife with Particular Reference to the House Wren (*Delichon urbica*)[1]

James R. Newman, Ph.D.[2]

Abstract: Injury and death to wildlife from air emissions have been recorded since before the turn of the century. Air pollution can directly affect wildlife (i.e., cause death), or can indirectly affect wildlife (i.e., cause habitat loss). A recent investigation on the chronic and sublethal effects of air pollution on the house martin (Delichon urbica) has shown that air emissions can significantly affect the nesting ecology of this species.

INTRODUCTION

Since the end of the 19th century, over 100 air pollution episodes have been reported involving injury and death to animals (Newman 1975, 1979). Although the majority of the incidents involved domesticated animals, a number of incidents have been reported for wildlife since the 1880's (table 1). Overall, the few reports involving wildlife appear to be more a function of economic bias to report injury and death of domestic animals than some innate resistance of wildlife to air pollution. For example, in the early 1900's arsenic emissions from a smelter caused the injury and death of several thousand cattle and horses in rural Montana (Harkins and Swain 1908). No mention was made of injury or death to deer or other wildlife plentiful in the area, although deer and rabbits are known to be very sensitive to arsenic emissions (Prell 1936; Hais and Masek 1969). Eighty-five percent of the wildlife incidents have been recorded in the last 25 years. The increase in the number of wildlife incidents appears to be due not only to an increase in air emissions but to a better understanding of air pollution effects, broader communications, and a greater interest in reporting such problems.

Table 1--The number of reported air pollution incidents involving wildlife and affected groups (adapted Newman 1979)

Period	Number of Incidents	Wildlife Groups: Game	Wildlife Groups: Nonegame	Consumer Groups: Prim.	Consumer Groups: Secondary
Before 1900	1	1		1	
1900-1950	3	3	2	5	
1951-1970	8	4	7	8	7
1971 to Present	17	7	15	15	8
TOTAL	29	15	24	29	15

[1] Presented at the Symposium on Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, June 22-27, 1980, Riverside, California, U.S.A.

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Recent Federal legislation, namely the 1977 Clean Air Act Amendments, now require formal consideration of the effects of air emissions on wildlife and other components of ecological systems.

The purpose of this paper is to summarize some of the known effects of air emissions on wildlife and present preliminary findings on the ecological effects of air emissions on the house martin (Delichon urbica), an insectivorous bird. For this paper, discussion is limited to terrestrial wildlife and vertebrate consumers. Previous speakers here discussed the effects on invertebrate consumers.

GENERAL EFFECTS OF AIR EMISSIONS ON WILDLIFE

One of the earliest wildlife incidents (1887) involves the death of fallow deer (Dama dama) from arsenic emissions from a silver foundry in Germany (Tendron 1964). As early as 1900 the Royal Society of London was charged to investigate the phenomenon of industrial melanism. This incident is recognized more for its demonstration of "natural" selection than as an environmental problem. Recently, genetic changes in small mammals because of air pollution have been reported (Newman 1980).

One of the earliest detailed descriptions of the harmful effects of air emissions on wildlife is from Germany. Arsenic emissions were the cause of widespread death of game animals in the Tharandt forest of Germany in 1936. Sixty to seventy percent of the red deer (Cervus elephus), roe deer (Capreolus capreolus), and wild rabbits (Oryctolagus cuniculus) died. The deer exhibited defective hair growth and antler formation, cirrhosis of the liver and spleen, and emaciation (Prell 1936).

Adverse effects of air emissions on wildlife have been reported from North America, Europe, and Asia, and have included game and nongame animals; birds and mammals; primary and secondary consumers; and herbivores, omnivores, and carnivores (table 1). The effects on wildlife have included die-offs and other population reductions, physiological abnormalities, disease, physical injury, and bioaccumulation. The majority of wildlife incidents reported involve deer and small birds (Newman 1979). These groups are not necessarily more sensitive but are more likely to be monitored, especially deer, which is a widely managed game species. The status of small birds is not only of scientific concern, but also of more widespread public interest.

Pathways of contamination by air emissions for wildlife are: inhalation, adsorption, and ingestion. Wellings (1970) reported the occurrence of pulmonary anthracosis in urban sparrows (Passer domesticus) compared to rural populations in California. One of the most startling examples of contamination by inhalation involved the die-off of 200 to 500 songbirds near a British Columbia pulp mill which emitted high concentrations of H_2S and other pollutants. The dead birds showed internal hemorrhaging in the lungs and liver.[3]

Adsorption of air emissions involves the adhesion of gases or particulates to the external surfaces or external membranes, e.g., cornea of eyes. Light (1973) reports a high incidence of blindness in bighorn sheep (Ovis canadensis) found in mountain areas of California with heavy oxidant levels. Oxidants are known eye irritants. Investigators in Czechoslovakia[4] have observed early aging of the cornea in hares (Lepus europaeus) found in areas with heavy SO_2 and particulate deposition from power plants and other industries.

Ingestion is the most commonly reported mode of contamination for wildlife. Injury and death to wildlife from ingestion of contaminated food and water have been reported for numerous animal species including rabbits and deer from arsenic emissions (Prell 1936), deer from fluoride emissions (Karstad 1967; Robinette and others 1956; Newman and Yu 1976), and sparrows from cadmium emissions (Nishino and others 1973). There are many reports of the bioaccumulation of air pollutants in wildlife. With a few exceptions, the effects of this bioaccumulation are not known (Newman 1980).

Air emissions may not be lethal to wildlife but may lower the health and resistance of wildlife so that natural stress such as cold and shortage of food may result in further injury or death. Studies on the health of wild hares (Lepus europaeus) living in areas of high air pollution in Czechoslovakia showed physiological responses similar to animals with infections or allergic reactions. There were also changes in the normal age structure of the hare populations (Novakova 1969). The general health of deer populations affected by fluoride emissions is poor (Robinette and others 1957; Karstad 1967; Newman and Yu 1976; Newman and Murphy 1979). Th[e] survival of these deer during times of natural stress is questionable. Hais and Masek (1969) report that arsenic contamination of red and ro[e] deer caused emaciation and loss of hair so that many of the animals froze to death during the winter.

Injury or death to vegetation caused by air emissions can have significant indirect effects on wildlife. The loss of food resources and habitat can occur as the result of injury or

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[3]Unpublished report, R.D. Harris 1971. Birds Collected (Die Off) at Prince Rupert, B.C. Canadian Wildlife Service, Prince Rupert, Briti[sh] Columbia.

[4]Personal communication from Eliska Novakova, Institute of Landscape Ecology, Pragu[e], Czechoslovakia.

death to vegetation which provides cover, reproductive habitat, or food for wildlife. Many examples exist of extensive damage to ecosystems from air emissions. Large areas of the mixed coniferous forest of southern California (over ,0,000 hectares) have been killed or injured from hotochemical oxidants (Taylor 1973). No overall ssessment has been made as to the loss of ildlife whose forest habitat has been destroyed. imilar large wildlife habitat losses have ccurred in Montana, Tennessee, British Columbia, nd Ontario, Canada (Newman 1980).

ECOLOGICAL EFFECTS OF AIR EMISSIONS ON THE HOUSE MARTIN

With few exceptions, there is little nformation available on the effects of chronic :posure of wildlife to air emissions (Newman 980). Since 1976, RNDr. Eliska Novakova, CSC, om the Institute of Landscape Ecology, Prague, d myself have been studying the ecological sponses of the house martin (Delichon urbica) chronic air pollution. In this portion of the lk I would like to present some of our eliminary findings.

The house martin belongs to the family rundinidae. It is an insectivorous bird which eds primarily on aphids and diptereans. A gratory species, the martin summers throughout rope and winters in Africa. As a colonial sting species, it builds mud nests on the walls buildings. The nesting locations are used ch year, often by the same birds.

Previous studies have indicated that D. urbica sensitive to air pollution. Feriancova-arova and Kalivodova (1965) observed changes the species diversity of birds, including the se martin, in the area of an aluminum plant in choslovakia. Cramp and Gooders (1967) erved a correlation with increased nesting of urbica and a decrease in smoke pollution in don. A follow-up study (Newman 1977) in the inity of the same aluminum plant studied by iancova-Masarova and Kalivodova in 1965 showed t D. urbica decreased its nesting density with reased air emissions.

In 1978 direct counts of active nests were e in 141 villages and towns located in ustrialized (contaminated) and -industrialized (control or background) areas. the 141 nesting localities censused, villages and towns were influenced by air ssions from various industrial sources. r plants and associated surface mines, ical plants, local heating plants (coal ing), cement plants, and general urban ssions sources were the major air emission uences. Censusing was conducted at pre-rmined upwind and downwind locations from an sion source. This census represented rvations of over 20,000 buildings. Records kept of the number of active nests. A standard nesting density measure was derived as well as measures of the occupancy of a nesting location and colony size. The environmental attributes of each nesting locality was characterized. Comparisons of background nesting localities were then made to ecologically similar, but contaminated, nesting localities.

The mean nesting density of D. urbica from control areas was 0.565 ± 1.94 nests per side. The range in colony size was 1 to 33 active nests per occupied side, with an average colony size of 2.7 ± 1.1 active nests per occupied side. The average occupancy (the number of occupied sides per suitable side) for the 32 background nesting areas was 21.0 ± 8.1 percent.

The overall nesting density for D. urbica from contaminated areas was 0.393 ± 0.734 active nests per suitable nesting side. This nesting density (30 percent) was significantly lower ($t_{0.002} = 3.674$, df = 8968) when compared to background nesting sites. Occupancy was only 13.6 percent. Attempts at nesting were also lower, with only 0.74 attempts per contaminated village compared to 1.12 attempts per background village. Colony size was significantly lower (2.1 ± 1.5 active nests per occupied side).

The house martin responds also to the level of air emissions. The overall nesting density for downwind locations was 0.237 ± 0.378 (n = 4891) nests per side compared to 0.415 ± 1.603 (n = 1969) nests per side for upwind localities. This difference was significant ($P < 0.001$; t = 7.263; df = 6808). The overall upwind nesting density was not significantly different from background areas.

Colony size and occupancy also changed with proximity to emission sources. Upwind colony sizes averaged 2.5 ± 1.0 nests per occupied side compared to 1.8 ± 0.8 nests per occupied side for downwind locations. These differences were significant ($P < 0.001$; t = 3.492 df = 99). Upwind occupancy (18.8 ± 8.9 percent) was also significantly higher ($P < 0.001$, t = 5.70, df = 99) when compared to downwind occupancy (9.1 ± 7.7 percent).

The nesting density for downwind locations decreases significantly as the distance to the emission source decreases (table 2). For upwind locations, the closer to the source, the higher the nesting density; for increased distances, nesting densities declined. The upwind nesting densities closest to emission sources were not significantly different from background nesting densities. Colony size was lower at all downwind distances, but only significantly lower at the two closest distances. Occupancy was significantly lower for all distances censused downwind. For the two closest upwind distance groups (out to 6 km), both colony size and occupancy were not significantly different from background conditions.

Table 2--Comparison of nesting density of *D. urbica* at various distances upwind and downwind from emission sources

Location	Sample Size (No. of Sides)	Mean Nesting Density	Percent Difference From Background
Downwind			
0 to 3 km	1451	0.187 ± 1.046	[1] -66
3.1 to 6 km	1162	0.213 ± 0.966	[1] -62
6.1 to 9 km	773	0.260 ± 1.323	[1] -54
9.1 to 12 km	252	0.286 ± 1.425	[1] -49
Upwind			
0 to 3 km	531	0.589 ± 2.508	[2] + 4
3.1 to 6 km	493	0.550 ± 1.771	[2] - 3
6.1 to 9 km	583	0.293 ± 1.020	[1] -42
9.1 to 12 km	59	0.372 ± 1.193	[1] -33

[1]Significant, $P < 0.025$.
[2]Not Significant, $P<0.05$.

The air dispersion patterns associated with the stack heights influenced the observed effects. For sources with high stacks (greater than 100 meters) the adverse effects on nesting were observed in both downwind and upwind localities. For downwind locations, the lowest nesting density did not occur closest to the emission source, but at an intermediate distance (3 to 6 km). Nesting density was significantly depressed out to 12 km. For low stack sources (less than 100 meters), the lowest nesting density, colony size, and occupancy occurred at the closest distances (0 to 3 km). Average nesting densities were 20 percent of background. In contrast to high stack sources, the nesting density influenced by low stack sources was near normal at the 9.1 to 12 km distance categories. For upwind localities, emissions from high stack sources have an adverse influence, especially close to the source. For low stack localities, upwind nesting densities were either at or above background levels at all distances censused.

When the house martin nests in optimum nesting conditions, such as apartment buildings and feedlots in proximity to water, the effects of air emissions were mitigated. The greatest adverse effects on the nesting ecology of *D. urbica* were observed surrounding power plants and open surface mines. Chemical plant emissions had the next most significant effect on the house martin.

In summary, sublethal and chronic levels of air emissions from industrial sources, such as power plants and chemical plants, adversely affect the nesting ecology of *D. urbica*, including a reduction of the nesting density, colony size, and occupancy of this species. The greatest effects on the nesting pattern of *D. urbica* were observed in areas downwind from the emission sources and at decreasing distances from the air emission sources (fig. 1). For low stack emission sources, greatest effects were observed in the immediate vicinity of the stacks where the highest emission levels are expected to occur. For high stack sources, greatest effects were observed at intermediate distances from the stacks and a greater distance than observed in low stack localities.

Evidence suggests that wildlife populations living in optimal habitat conditions are less affected by air emissions than wildlife populations living in less than optimal conditions. This observation has particular importance for the management and preservation of endangered species.

Overall the effects of air pollutants on wildlife can be dramatic, such as the die-offs, or quite subtle, such as shifts in the age structure of populations. In many cases the effects have been debilitating injuries, often contributing to the death of animals during periods of natural stress. Air emissions can also reduce wildlife populations not only directly, but indirectly through loss of habitat.

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Chronic Effects of Acidic Precipitation and Heavy Metals on Forest Ecosystems

The Acidity Problem—Its Nature, Causes, and Possible Solutions[1]

Lowell Smith[2]

Abstract: Interest within the scientific community in North America and Europe about the nature, effects, and causes of atmospheric acid deposition has grown rapidly over the past decade. This interest has recently intensified because of the explosion in public awareness of, and concern over, the acid deposition problem, and a growing political will to address the problem within appropriate national and international forums. This paper sketches the nature of the acid deposition problem; describes the atmospheric processes that convert precursor emissions into acidic compounds as these are transported over distances ranging from a few to more than a thousand kilometers; discusses past and possible future trends in geographical distribution and rate of acid deposition; and summarizes the governmental activities which have been initiated to address the problem.

The scientific study of acid deposition is archtypical of many contemporary environmental problems, in that it necessarily covers a wide spectrum of disciplinary interests. Simply listing the many subdisciplines involved would fill more than a page. It is important for the active research worker in the field to recognize the many interconnections between her or his own endeavors and other research areas. This involves a careful balance because, at the same time one is encouraging a cross-fertilization of ideas among various disciplinary efforts, one must guard against extending scientific judgements beyond one's own limits of competency. Since the author is fully aware of this hazard, he invites reaction from any who take exception to the summaries presented in this paper.[3]

The major features of acid deposition are:

- acid deposition results primarily from the combustion of fossil fuels which releases sulfur dioxide (SO_2) and nitrogen oxides (NO_x) in the form of nitric oxide (NO) and nitrogen dioxide (NO_2) to the atmosphere;
- depositing acidic material is formed out of these precursor emissions by means of a large number of chemical reactions as the emissions are transported away from their source region;

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[3]The views expressed in this paper are those of the author and do not necessarily reflect those of the Environmental Protection Agency.

- acidic material is deposited dry in the form of fine particulate matter and is incorporated into all of the possible physical forms of precipitation;

- transport distances between source and receptor regions can exceed a thousand kilometers, although a major source can, on occasion, significantly affect the rate of acid deposition within the first few kilometers downwind of the source; and

- the effects of the deposited acid can vary markedly, depending upon the form in which the acid is deposited, the biologic, geologic and hydrologic pathways between deposition site and the receptor of interest, and the sensitivity of the receptor.

'his paper explores these major features ·f acid deposition.

ature of Acid Deposition

Acidic compounds may be deposited by everal forms of precipitation (rain, now, hail, dew, rime, and mist) as well s by fine particles that settle out of he atmosphere on to biologic, mineral, nd aquatic surfaces, and on to man made aterials, buildings, and artistic objects. ecause monitoring techniques are not ell developed for measuring and characterzing the dryfall component of acid deposiion, comparatively little is known bout its extent and variability (Durham d Hicks, 1980). Monitoring data from astern North America indicates that the ilfate ion is the predominant anion esent in acidic precipitation; the itrate ion is associated with about alf as much acidity as the sulfate ion, d chloride and other anions make subantially lower contributions (Hales, 980). In some areas of the West the trate ion contributes an equal or rger share than the sulfate ion (McColl, 980; and Morgan and Liljestrand, 1980).

Some regional scale atmospheric models timate that up to half of the sulfate mponent may be deposited dry, while her models estimate a lower percentage helpdale and Galloway, 1979). The riance results from a basic lack of derstanding of the physical, as well biological processes, and their variaion over space and time, as these processes ansfer gases and particles across the mosphere/surface interface (Durham and Hicks, 1980). In addition, nitric acid depositing onto surfaces out of its vapor phase may at times be an important contributor to dry deposition; but even less is known about its ambient concentration and geographical distribution (Altshuller, 1979). Thus, until monitoring techniques are developed for routine reliable measurements of dryfall deposition, we are compelled to rely on isolated spot measurements and tentative inferences to characterize this important phenomenon.

The characterization of wet deposition is a more tractable problem. While it is doubtful that precipitation at any place on the globe is entirely free of anthropogenic contaminants, relatively "clean" rainfall is generally found on the windward edge of continental land masses and where frontal storm systems have traversed large expanses of sparsely populated land surfaces (Granat, 1978). Because of the formation of carbonic acid from the hydrolization of background atmospheric carbon dioxide, such clean rainfall is thought to have a pH of about 5.6, approximately 25 times more acidic than a neutral pH of 7 (Likens, et. al., 1979). Yet even the pH of rainfall relatively unaffected by anthropogenic emissions can vary by several pH units due to the entrainment of alkaline soil particles, reaction with atmospheric ammonia, and possibly other little understood factors (Stensland, 1979).

The concentration of acidity in precipitation is observed to be quite episodic (Smith and Hunt, 1979), which combined with the episodicity of precipitation rates, leads to great variability over space within a particular rain event and over time at a particular location of the rate of acid deposition (Hales, 1980). A range of over seven orders of magnitude of acidity (pH 2 to pH 9) has been recorded for various isolated rainfall events in North America. Averaged over time, spatial variations tend to vanish at locations distant from large sources. An exception is the orographic effect produced by high terrain features on precipitation rates. This effect can be further augmented by the increasing acidity of cloudwater at higher elevations within a cloud structure (Falconer and Falconer, 1980). Terrain subject to orographic precipitation in North America and Europe, such as the Nothern Alps, that is downwind of high emission areas has been observed to sustain substantially increased quantities of deposited acidic material than similarly situated low lying terrain (Schrimpff, 1980).

Averaging wet acid deposition rates over an annual cycle for monitoring stations in eastern North America produces a pattern of depressed pH values in the northeast United States (Pack, 1980) extending northward into southern Ontario and Quebec, westward to the eastern Midwest, and southward along the Appalachian ridge into Tennessee and the Carolinas. Less depressed average pH levels extend deep into Florida (Brezonik, et. al., 1980), west to Arkansas and Missouri, and northward an undetermined distance into Canada (Likens and Butler, 1980). The average acidity of precipitation in the central portion of this pattern approaches pH 4, approximately a factor of forty more than what many consider to be the "normal" value of pH 5.6 (Likens and Butler, 1980).

Due to the spottiness of available monitoring information less is known about acid deposition rates west of the Mississippi River. Measurements made in the Boundary Waters Canoe Wilderness Area (northern Minnesota) (Glass and Loucks, 1980), the Colorado Rockies (northwest of Denver) (Lewis and Grant, 1980), and California (the Sierra Nevada, and the Los Angeles and San Francisco Bay basins) (McColl, 1980; and Morgan and Liljestrand, 1980) all suggest that this problem is not unique to the eastern half of the continent.

Effects of Acid Deposition

Acid deposition creates a public policy problem to the extent that potentially sensitive receptors are harmed by the deposition rates they sustain. Research results on acid deposition effects are multiplying rapidly in North America and Europe (International Conference on the Ecological Impact of Acid Precipitation, 1980). An impressive body of information now exists as to the impact of acidifying surface waters on the ecosystems they support (Gorham, 1976). Some fish species show adverse effects below pH 6; while other more tolerant fish species do not evidence serious effects until pH 4 or lower has been reached. Eggs and especially the fry of sensitive species are more susceptible than are adult fish (Johannson, et. al., 1977). Thus, during the initial melting of a snowpack, acid pulses may be released which abnormally skew subsequent fish population distributions to the extent that one or more generations may be completely absent in some instances. Other portions of aquatic food chains can also be affected to the detriment of wildlife species at the top of these chains, including fish eating birds (Peakall, 1980) and freshwater wading birds (Loucks, 1980).

Recent evidence from Europe suggests that leaching of calcium and other nutrients from the lower horizons of sensitive soils and the concomitant mobilization of Al^{3+} ion within these soils (Ulrich, 1980) is promoted by atmospheric acid deposition. Also observed is a reduction of the decomposition rate of forest litter and decreased numbers of micro-organisms (Baath, et. al., 1978) within the upper soil horizons of forest soils subjected to heavy rates of acid deposition. In extreme cases ground water quality may be adversely affected (Hultberg and Wenblad, 1980). Abnormally low pH for drinking water supplies drawn from wells in some of these regions has been observed. This can result in unacceptably high concentrations of copper and lead in drinking water in those homes which are equipped with copper plumbing systems (Hultberg and Wenbald, 1980).

Agricultural crop species cultured in pots and subjected to lowered pH simulated acid rain irrigation water have displayed mixed responses in yield (Lee, et. al., 1980). Some cultivars exhibit enhanced yields and others depressed yields while many cultivars show no discernible effect on yield. The effect of acidic deposition on forest growth rates is more uncertain. Early stages of acidification can accelerate growth rates for a few years, possibly due to the increased mobilization of nutrients within the soil structure. But sustained elevated rates of acid deposition are hypothesized to depress forest growth rates in geologically sensitive areas due to nutrient depletion and elevated concentrations of Al^{3+} ion within the root zone. Other ecological effects are discussed elsewhere (Overrein, 1980, Norton, et. al., 1980, and Cowling, 1980).

Mechanisms of Atmospheric Formation

As previously stated, acid deposition is primarily the result of the anthropogenic release of SO_2 and NO_x to the atmosphere where these react through several available chemical pathways to sulfuric and nitric acids. To a lesser extent hydrochloric acid can also be involved. Coal and oil fired electric utility generating stations, predominantly in the central and eastern portions of the U.S. are responsible for two-thirds of the national SO_2 emission inventory (U.S. EPA, 1979a). Nine-tenths of these emissions are from coal-fired stations. Industrial and commerical boilers account for nearly half of the remaining emissions. SO_2 emissions in the U.S. are likely to increase slowly over the next few decades as emissions from well-controlled new sources slightly overbalance emission reductions expected to be achieved by the control or retirement of existing sources (Altshuller and McBean, 1979). Canadian SO_2 emissions come predominantly from their non-ferrous smelter industry at present, but by the end of the century coal fired utility boiler emissions are expected to about equal those from the smelter industry (Choquette, 1980).

Two-fifths of the nation's NO_x emissions come from motor vehicles. Geographically, these mobile sources are clustered around large population centers. Nine-tenths of the remaining NO_x emissions are released by the same large utility and industrial boilers which are responsible for the predominant portion of the SO_2 inventory (U.S. EPA, 1979a). NO_x emissions are expected to increase significantly in the U.S. and Canada over the remainder of the century

unless some promising breakthrough in NO_x emission controls is achieved and rapidly implemented by industry (Altshuller and McBean, 1979).

Although no emission inventory exists for chloride ions, these emissions are likely to be primarily the result of burning high chloride coals produced from many coal seams in the midwestern and eastern U.S. Therefore, chloride emissions are likely to be colocational with large SO_2 and NO_x emitting sources. Natural emissions of SO_2 (Adams, et. al., 1980) and NO_x[4] make only modest additions to the anthropogenic sources in eastern North America, though natural emissions may make an appreciable contribution to the global background of these atmospheric constituents (Husar, et. al., 1978).

These precursor emissions react in the atmosphere with water vapor, other minor atmospheric constituents and sunlight to produce fine sulfate particles, nitric acid vapor and dilute acids in cloud droplets. These submicron particles agglomerate into larger particles until a natural barrier to further growth is reached at slightly above one micron mean diameter. The growing particle may be deposited in dry form onto a surface, incorporated into a cloud droplet (rainout), or scavenged by a falling raindrop (washout) (Hales, 1980). The hydroxyl ion in conjunction with sunlight is believed to promote the formation of particulate sulfate (Davis, et. al., 1974), while the peroxyl ion is believed to promote the conversion of SO_2 to sulfuric acid in cloud droplets.[5]

In the summer months, substantially enhanced concentration of sulfate ion are found in deposited rainwater while nitrate ion concentrations tend to be more constant throughout the year (Hales, 1980). There is some evidence to suggest that nitrogen oxides are deposited more rapidly from the atmosphere on the average than are sulfates (Mueller, et. al., 1979), so nitric acid deposition may be relatively less important for receptor sites far from emission regions than is sulfuric acid deposition.

Another complicating feature in the atmospheric chemistry of acid deposition is the atmosphere's ability to partially neutralize its acid load. Alkaline fine wind blown soil particles, particularly over arid regions, appear to neutralize the acid load (Eisenreich, et. al., 1980), or create aerosols with basic chemical properties. The ammonium ion is also effective in partially neutralizing dry and wet atmospheric acidic materials. Many natural and anthropogenic sources produce ammonia, but a complete ammonia emissions inventory has yet to be constructed. Stockyards, municipal waste water treatment plants, certain industrial processes, and decaying vegetable matter are among its important sources.

Some investigators have hypothesized that fly ash from coal combustion has historically played a major role in reducing atmospheric acidity and that recent efforts to control fly ash emissions have noticeably worsened the acid deposition problem (Frohlinger and Kane, 1975). Such an effect is unlikely to have been nearly as important as was once supposed. As will be discussed later in this paper it is unclear what the historic trends for deposited acid are in the Northeast. Thus, such an ad hoc explanation may not be relevant to explain what is an inconclusive trend. More importantly, considerations such as the size of fly ash particles relative to the size of sulfate particles, the chemical composition of fly ash from midwestern and eastern coals, and the change from stoker-fired coal boilers to pulverized coal boilers during this period, all suggest that the neutralizing effect of emitted fly ash could only have been important in the immediate locality of a relatively few heavy fly ash emitting sources.

Mechanisms of Atmospheric Acid Transport

Several physical processes are important to the atmospheric transport of acid precursors and their acidic products. Particularly important for the SO_2/sulfuric acid/sulfate complex is the elevated height of injection into the atmosphere level for SO_2 emissions from most major power plant sources. A nocturnal inversion layer frequently isolates these tall stack plumes from the ground (Smith, et. al., 1978) until after sunrise when the incident solar energy begins to mix the atmosphere through the activation of convective cells. In the Midwest during summertime conditions, a nocturnal bulge in the wind speed vertical profile is frequently observed at normal tall stack plume heights. This condition can transport emissions from a tall stack several hundred kilometers overnight (Smith, et. al., 1978). The gas to particle conversion of the emissions in this displaced plume can be greatly accelerated the next day as these transported emissions are mixed with a polluted urban air mass.

The highest ambient concentrations of particulate sulfate are observed under summertime conditions when a synoptic scale high pressure system stalls for more than a day over a region of high SO_2 emission density, such as the Ohio River Basin (Hidy, et. al., 1978). In this situation weakly circulating winds can trap a large air mass while it is being continually filled with precursor emissions (Vukovich, 1979). The higher temperature, moisture and sunlight levels generally encountered under these conditions tend to increase the chemical reactivity of the atmosphere, so the higher concentration of precurser emissions can more rapidly be converted to particulate sulfate.

[4]Personal communication from Dr. Rudolph Husar, August 15, 1980, Washington, D. C.

[5]Personal communication from Dr. A. L. Lazrus, July 21, 1980, Washington, D. C.

A common atmospheric cleansing mechanism for this condition is for a cold front to approach the high pressure center from the north or northwest (Whelpdale, 1978). This creates a strong pressure gradient which sweeps much of the polluted air mass parallel to the line of the front for many hundreds of kilometers, frequently to the northeast. (LaFleur and Whelpdate, 1977). Frontal storm activity can further remove considerable amounts of pollutants as rainout and washout. Similarly, large convective storms are believed to be an efficient mechanism for processing and removing pollutants from the large volume of air they entrain. These storms are capable of pumping large quantities of polluted air from the planetry boundary layer to high elevations where these can be left as isolated patchy layers to be transported considerable distances and eventually deposited.

Alternating periods of stagnation and ventilation over a high emission area produce episodic concentrations of pollutants (Ottar, 1978) which result in highly variable acid deposition rates in downwind regions. Likewise, the variability in wind direction, as it guides and mixes isolated plumes from major sources and the regional scale plumes described above, adds to the temporal variability of deposition rates at any monitoring site. Thus, acid deposition must be viewed as a stochastic process which, in areas not under the influence of a major source and not affected by orographic terrain effects, is temporally and spatially chaotic over a small scale but is rather spatially homogeneous within a given region when averaged over a large number of events.

Historical Trends in Acid Deposition Rates

While the routine measurement in a scientifically reliable manner of wet deposited acid has only recently, with the exception of a very few monitoring stations, been undertaken in this country, it has been practiced in several European countries over a longer period of time (Granat, 1978). Both the European and North American experiences have demonstrated the need for strict quality assurance procedures for collecting and analyzing the rain water samples. Failure to establish sufficiently stringent quality assurance procedures early in monitoring programs has created questions about the validity of much of the early data (Tyree, 1980).

The need to calculate retroactively the acidity of monitored rainfall using one of several ion balancing procedures, has compounded these measurement difficulties since acidity or pH was usually not measured directly (Kramer, 1978). Such procedures can propogate the experimental uncertainties, which were introduced by the collection and laboratory procedures employed, into rather sizable uncertainties in the calculated hydrogen ion concentration. Further careful analysis of all available rainwater chemistry monitoring data is required in order to establish the level of certainty with which historical trends of acid deposition in North America can be determined.

Fortunately, it may be possible to describe the gross features of deposition trends by relying on other related physical phenomena for corroborative support. Since sulfate aerosols are highly efficient light scatterers due to their characteristic submicron size, and since sulfate is the dominant component of Eastern aerosols (U.S. EPA, 1979b), visibility trends probably serve as a useful indicator for dry sulfate deposition trends. The ratio of dry to wet sulfate deposition should have remained relatively constant for a particular area unless a climate change has occu

Visibility measurements have been routinely made at medium and large size airports in the U.S. for several decades. Recent analysis of these data shows that summertime visibility has significantly deteriorated throughout large portions of the eastern U.S. (Trijoni and Shapland, 1979). Some regions such as the Tenness Valley appear to have sustained nearly a factor of two decrease in average summertime visibility over a twent five year period (Husar, et. al., 1979). Similar tren in summertime solar insolation are also suggestive of a increase in atmospheric turbidity during this sam period. Further analysis effort is required to assess the possible causal relationships between trends in precursor emission rates and these trends in environmental conditions.

Although the trends of such surrogates for acid deposition may only be used to corroborate an inconclusive record for monitored acid deposited, other studies strongly support the conclusion that anthropogenic emissions are deposited on ecosystems far from their point of origin. Dated lake bottom cores from remote lakes in North America and Greenlan icecap cores show a marked increase in deposition rates for fossil fuel combustion-related pollutants shortly after the beginning of the industrial revolut

A review of emission trends from U.S. sources over the past forty years indicates several clear trends. First, SO_2 emissions increased about forty percent. Although SO_2 emissions have decreased from most economic sectors during this period, the electric utility sector's emissions increased by more than a factor of six during this same period (EPA, 1978). Second, the increase in SO_2 emissions from this one sector occurred concurrently with a substantial increase (by approximately a factor of five) in the stack height for utility sources. Thir SO_2 emissions from coal burning changed from a wintertime peak to a summertime peak in emission rate (Husar, et. al., 1979). Fourth, the precursor emissions for photochemical oxidants increased markedly during this time (EPA, 1978). At the beginning of the period photochemical smog was hardl recognizable as a problem, whereas, currently urban plumes of photochemical oxidants now frequently blan the Northeast during the summer months (Altshuller, 1978). Fifth, total NO_x emissions approximately quadrupled during this period (EPA, 1978).

These trends suggest a situation in which e atmosphere has become chemically more active, and for which greater quantities of id-forming precursors are added to the atmosphere ring its most reactive period. Further, a ostantially greater quantity of these emissions now injected high into the mixed layer where emissions and their reaction products have ch longer residence times as they travel to eas remote from their point of origin.

sible Solutions

At present there are no regulatory requirements t are primarily directed at reducing emissions control acid deposition. However, the an Air Act's requirement to reduce ground el SO_2 concentrations has achieved modest rall reductions in SO_2 emissions during first part of the past decade (U.S. EPA, 9a). But, average stack heights continued increase, as did the emission rates for , over this period. Regulatory requirements ablished for new coal-fired utility boilers date control of seventy to ninty percent of ir SO_2 emissions and require NO_x emission uctions of approximately forty percent S. Federal Register, 1979). EPA is currently eloping new source control performance ndards for industrial boilers which could uire similar levels of control for this ortant source category. From a regulatory spective the principal problem for SO_2 ssion control is the control of emissions existing sources. In addition, there are e opportunities for improved NO_x control uirements for new and existing sources.

thers have maintained that the costs of sion control are so high that the only -effective mitigation measure is to raise fically the pH of affected lake water by addition of lime (Barnes, 1979). Repeated tments would be required as long as acid sition rates exceeded the geologically rolled release rates for a given area n, et. al., 1980). Recent Swedish exper- e indicates that liming the entire watershed a lake may be necessary, while others eve that even though it is possible to e the pH of an acidified lake, it is not sible to restore the lake to a natural ition containing its original food chains. rs have observed that the potentially itive areas in North America cover millions ectares, and question the feasibility of ng such a vast area for hundreds of years.

ederal government efforts to address acid deposition problem include:

- monitoring activities to establish more fully the geographical variation and temporal trends in rainwater chemistry;
- research activities to determine more completely the range of environmental effects produced by acid deposition and the atmospheric processes which transport and convert emissions into acid deposition;
- assessment activities to determine the potential seriousness of the acid deposition problem in North America and the most cost-effective measures that could be employed as first steps to combat the problem;
- the creation of a ten year inter-agency Federal Acid Rain Assessment Program to coordinate the above activities;
- working with the states in order to promote a mutual understanding of the nature and causes of the acid deposition problem, and to encourage the states to engage in collective problem solving on this issue; and
- becoming a signatory to an international Convention on Long-Range Transboundary Air Pollution, developed under the auspices of the United Nations Economic Commission for Europe, and pursuing bilateral discussions with Canada which are expected to evolve into formal negotiations on a U.S.-Canada bilateral transboundary air pollution agreement.[6]

Such efforts cannot be expected to bring about immediate and complete relief from the acid deposition problem - nor are they designed to achieve this objective. Rather the goals are to establish as quickly as is feasible a scientific basis for understanding the full range of receptors at risk and the extent of risk to each receptor category; to determine the extent of the control measures which are required to reduce the acid deposition problem to an acceptable level; to develop new air pollution control policies and strategies as necessary and appropriate; and to promote full cooperation and understanding across interstate and international borders to deal effectively with this complex and challenging problem.

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[6]Note added in editing: A Memorandum of Intent was signed in Washington, D. C., on Aug. 5, 1980, by the two governments in which they agreed to initiate formal negotiations by June 1, 1981.

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Acid Precipitation Impact on Terrestrial and Aquatic Systems in Norway[1]

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Abstract: In recent decades the acidity of rain and snow has increased sharply over wide areas. The principal cause is the release of sulphur and nitrogen oxides by the burning of fossil fuels. The air quality in any one European country is measurably affected by emissions in other European countries. Strong acids have lowered the annual mean pH of precipitation in much of northern Europe to between 4 and 5. In southern coastal areas of Norway, the annual mean acidity in precipitation is now 4.3 pH-units, or even more acidic.

Acid precipitation has increased leaching of nutrients from the uppermost soil layers. These losses of nutrients may be expected to decrease plant growth, but field evidence in Norway and elsewhere, has not yet been obtained. It is possible that polluted air and precipitation over a period of years can influence plant production.

Atmospheric transport of sulphur and other acidifying components has led to extensive regional acidification of water courses in areas with very little neutralization capacity. Acidification of watercourses had had major effects on life in rivers and lakes. Lakes in an area of 13,000 km^2 in southern Norway have become empty of fish in recent decades, and a further area of approx. 20,000 km^2 contains lakes with significantly reduced fish stocks.

The ecological impact of acid precipitation has been a matter of growing concern over the last decade particularly in the industrialized countries of the Northern Hemisphere.

The Norwegian Interdisciplinary Research Programme "Acid Precipitation - Effects on Forest and Fish", (The SNSF-project) was initiated in 1972. In Norway acid precipitation was at that time seen as a possible cause of increasing acidity of the watercourses in the southern part of the country, and of the gradual disappearence of valuable fish populations from many lakes and rivers. It was also feared that the inputs of acid might over time reduce forest growth particularly through increased leaching of nutrient elements from the soil.

The SNSF-project has this year marked the conclusion of eight years of research by organizing the International Conference on the Ecological Impact of Acid Precipitation. This Conference, which was held in Sandefjord, Norway, March 11 - 14, 1980, attracted more than 300 participants from some 20 countries.

The present report is mainly a summary and brief

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discussion of the ecological impact of acid precipitation in Scandinavia with particular reference to Norway.

EMISSIONS, TRANSPORT, AND DEPOSITION

The concept of acid precipitation is now used to denote precipitation with high amounts not only of the hydronium ion (H^+ for short), but with enhanced concentrations of the acidifying anions sulphate, SO_4 and nitrate, NO_3, which predominantly stem from anthropogenic sources. "Acid" precipitation regularly also contains high amounts of ammonium, NH_4, and of various heavy metals and trace elements including organic micropollutants.

It should also be kept in mind that comparable amounts of anthropogenic pollution may be deposited by dry deposition processes from the same air masses giving acid precipitation. In studies of effects of acid precipitation the contribution from dry deposition is often difficult to quantify. In areas remote from the main industrial centres, like in Southern Norway, acid precipitation is more or less synonymous with long-range transported air pollution, but the distinction should always be observed. In our context, sulphur and nitrogen compounds giving rise to the acidifying properties of precipitation, are of prime interest, and their sources should be described with a view to finding their geographical distribution, emission rates and seasonal variation. This is necessary both for enabling modelling of their transport, and for formulating abatement policies against their negative effects.

Sulphur Emissions

Most of the man-made sulphur emissions occur as SO_2 from combustion of coal and petroleum products. Comparatively less stems from smelting of sulphur-containing mineral ores and other industrial processes, on a global basis about 10 percent. Knowledge of the location of industrial and powerproducing units in addition to population distribution has allowed quantification of annual emissions in a 150 km x 150 km grid over Europe (Semb, 1979). The main area of SO_2 emissions corresponds to the industrial belt from the Midlands in U.K., the Netherlands and Belgium, central and southern parts of Germany and Poland. Parts of northern France, Czechoslovakia and USSR also have industrial concentrations with very high emission rates. On a country basis, total SO_2 emissions in 1973 were estimated at e.g. $2.8 \cdot 10^6$ tonnes S from UK, 2.0 from the Federal Republic of Germany and 1.6 from France (OECD, 1977). Norwegian annual emissions were estimated at 91,000 tonnes of S.

Seasonal variations in SO_2 emissions occur as the demand for energy fluctuates through the year. At high latitudes the variable component of emissions is related to space heating and illuminatio during winter. In warmer climates, the maximum demand may occur during summer due to the use of air conditioning. In most of Europe, the fuel consumption will probably be at its peak in January - February. The seasonal variation is about 30 percent of the annual mean emission.

Nitrogen Emissions

Both nitrogen oxides, NO_x, and ammonium, NH_4, play important roles for the composition of acid precipitation. Although global budgets of nitrogen compounds are even more uncertain than those of sulphur, natural sources seem to be larger than the man-made. However, major man-made emissions also of nitrogen compounds occur in Europe and thus influence strongly precipitation chemistry in Scandinavia. The main anthropogenic source of nitrogen oxides is combustion of fossil fuels, by oxidation of nitrogen compounds in the fuel and oxidation of nitrogen in the combustion air.

It is well known that the NO_x emissions depen on fuel types, combustion chamber design and ope ating conditions. High combustion temperatures favour the emissions. There is, naturally, a hi spatial correlation between SO_2 and NO_x emission OECD studies indicated almost a doubling of anthropogenic nitrogen oxides emissions in Europe from 1959 to 1973, thus increasing more than sulphur dioxide emissions in the same period (OECD, 1977).

Trace-Element Emissions

Acid precipitation contains a wide range of minor and trace elements associated with the major chemical constitutents. Heavy metals, other trace elements and organic micropollutants of ma made origin are receiving increasing interest a some of these are enriched in living organisms.

Emission rates for trace elements and micropollutants are largely unknown, but the main sou ces are known . Many of the organic micropollutants in the atmosphere are products of human ac tivity, including industrial and waste products, and also chemicals used in industry as solvents or intermediate products. The emissions are ve complex mixtures of chemical compounds.

Transport and Deposition

Of particular interest for long-range pollutant transport is the build-up of high concent tions in stagnant air near the ground during inversion situations. Observations show that suc parcels of contaminated air may subsequently mo over long distances without much dilution. A much used technique in analyzing source areas a transport directions of air pollutants, is the sector analysis, grouping together trajectories belonging to the same sector.

Of considerable interest for the proportion of ;ulphate in acid precipitation to dry deposited ;ulphur components, is the oxidation rate from ;ulphur dioxide to sulphates. The oxidation :akes place both by absorption of SO_2 in cloud lroplets with subsequent oxidation, and by oxi- lation in the gas phase with oxygen compounds in he atmosphere. High concentrations of ozone and hotochemical oxidants, which are observed over arge areas of Europe, will increase the trans- ormation rate. The transfer of gases and par- icles from the air to natural surfaces, and the dsorption, are usually described in analogy with he theory of electrical resistance. The trans- ort from the atmosphere to the boundary layer lose to the surface, takes place by turbulent iffusion. The aerosol particles in question, .e., sulphur and nitrogen aerosols, are mostly n the 0.1 - 1.0 µm size range with low gravita- ional setting, and the turbulent transport will epend on meteorological conditions.

Model calculations of wet and dry deposition atterns over Europe show that in Scandinavia, articularly in Norway, the wet deposition out- eighs the estimated dry deposition. For southern orway dry deposition is estimated to account for bout 30 percent of the total deposition of ex- ess sulphate.

The precipitation in Norway is largely deter- ined by polar front lows bringing moist maritime r in westerly to south-easterly directions. Of rticular importance is the orographic enhance- nt of precipitation, caused by the lifting and bsequent cooling of the air masses when flowing ross the Scandinavian mountain chain. This ves rise to a maximum zone of elevated precipi- tion some 40 - 50 km from the coastline. In is zone, annual mean precipitation exceeds 00 mm along the SE coast increasing to an abso- te maximum of perhaps more than 5000 mm in north stern Norway. Still further north, in northern rway, annual precipitation in the maximum zone ceeds 2000 mm.

The group of macrocomponents typical of acid ecipitation, i.e. H^+, NH_4, SO_4 and NO_3, has a rked north-south gradient. The correlations tween sulphate, nitrate and ammonium are high, d there are roughly equivalent amounts of the incipal cations $H^+ + NH_4^+$ and anions SO_4^{2-} and N_3^-. The content of strong mineral acid in pre- pitation is strongly correlated with excess lphate. The correlation coefficient is 0.7 - 0 at Norwegian stations. At Norwegian stations N_3 makes about 30 percent of the sum $SO_4 + NO_3$. onium and nitrate occur in Norwegian precipi- tion in about equivalent concentrations, lowest mountain stations. The concentrations of S^{2-} and H^+ in precipitation are highest along south-east coast. The mountain plateau in thernmost Norway is affected by air transport m the south, which gives acid precipitation (4.5 - 5.0) as far north as 70^{o}N. lat. In thernmost Norway about 10 percent of the precipitation has a pH below 4.0 and about 5 percent above pH 5.0. Precipitation acidity below 3.5 has been observed several times at several places, Dovland and Semb, (1980).

Present knowledge of atmospheric deposition of inorganic trace elements in Norway is compiled by Semb (1978). They are found in the watersoluble fraction of aerosols, or absorbed on the other particles, and are mostly contained in the aerosol size fraction with aerodynamic mass diameter below 2 µm. Available data for lead, zinc and cadmium in precipitation shows a deposition pattern similar to that of excess sulphate. Also antimony, arsenic, selenium and vanadium seem to have similar deposition patterns. Influence from metallurgical industrial centres is evident for instance for chromium (western Norway) and arsenic, selenium, nickel, chromium and copper (smelting industry in the Murmansk area, U.S.S.R.). In northern Norway trajectory analysis shows that highly polluted episodes are often associated with the return flow pattern discussed by Rahn and McCaffrey (1980). Several studies of organic micropollutants in precipitation and in aerosols have been performed within the SNSF project. They have identified a wide range of compounds in the same air masses bringing acid precipitation to Norway.

ECOLOGICAL IMPACT

The effects of air pollution have historically been considered local problems, occurring near pollutants sources, usually urban areas. This concept of polluted cities versus clean rural areas is no longer applicable. The increase in anthropogenic emission sources coupled with the increased height of emissions have enhanced the phenomena of air pollution effects on rural areas. The most startling effects discovered so far of the long-range transmission of pollutants, have appeared in relatively remote, prisitine areas of Norway, Sweden and the Eastern United States and Canada.

Despite the fact that sulphur dioxide emissions to a large extent contribute to acid precipitation the two pollutants show great differences in effects. Sulphur dioxide is a primary air pollutant as well as a primary toxicant. Acid precipitation on the other hand, is a secondary pollutant causing mainly indirect effects on ecosystems.

Forest Ecosystems

The effects of air pollutants on plants is extremely diversified; it depends upon species-linked tolerance or susceptibility, and is a function of many exposure parameters (frequency, time, concentration, etc.). Many types of response have been described on the basis of laboratory experiments, where known chemicals were tested under controlled conditions with different plant species.

However, the inverse operation - namely identifying and estimating the nature and importance of an existing source on the basis of response symptoms - is often difficult, except in the case of acute injury and when a pollution source is known or suspected in the vicinity.

Vegetation damage due to the emission of acid and poisonous substances has long been observed in the vicinity of emission sources. Visible symptoms have been decribed and are often associated with the decrease in growth. Recently, however, concern has been expressed that forest growth may also be affected far away from emission sources. Even if the direct evidence is meagre, Tamm, (1976), there is fairly substantial indirect evidence that continued exposure to acid rain has a growth-decreasing effect. The most significant indirect evidence is the positive correlation between forest yield and the soil base status. Jonsson and Sundberg (1972) classified areas in southern Sweden as relatively resistant to acid rain and relatively susceptible to acid rain, respectively, and compared the growth trends in both areas by measuring annual rings on increment cores from groups of trees which were otherwise as identical as possible. They found a statistically significant difference and "found no reason for attributing the reduction in growth to any cause other than acidification." These results however, have not been confirmed by Norwegian researchers, Abrahamsen and others, (1976); Abrahamsen, (1980), Strand, (1980).

When evaluating the effect of acid precipitation on the supply of plant nutrients in a forest, a basis could be to consider the nutrient cycle in a terrestrial ecosystem. Plant available nutrients are generally supplied to the system from two sources; from the atmosphere, as for N and S, and from the minerals, as for Ca, Mg, P, K, S, and the micronutrients. In natural systems not harvested by man, nutrients are also lost in two ways: To the atmosphere by volatilization and to the sea by leaching. Evaluation of the effect of acid precipitation on the amount of plant nutrients in a forest ecosystem can therefore be restricted to the consideration of four processes; deposition from the atmosphere, weathering, volatilization and leaching from the soil. Obviously many processes in the soil and the plants can affect the accessibility of plant nutrients. Acid rain may affect some of these processes.

Experimental studies on tree growth in relation to acid rain have been conducted in recent years in several countries. As yet no conclusive evidence of decreased growth has evolved. On the contrary, a slightly positive growth effect on the seedling, which was explained as a nitrogen fertilizer effect, was reported by Wood and Bormann, (1975). Such increases, though, are likely to be temporary, as depletion of nutrient cations through accelerated leaching should eventually retard growth. Experiments on the effect of artificial acidification on forest growth under field conditions have been carried out in Sweden and Norway. The Swedish experiments have shown that increasing application of dilute H_2SO_4 has significantly increased the basal area growth, Tamm et al., (1980). The Norwegian studies consist of five field plot experiments where artificial rain has been produced by mixing groundwater and H_2SO_4 to pH values from 6 to 2. In one experiment with Scots pine, increased height and diameter growth was observed in 1976 and 1977 at the plots supplied with 250 mm of water per year of pH 3, 2.5 and 2. In 1979 however, the most acidified plots showed significantly less growth than the other experiments. (See Abrahamsen 1980).

The experiments thus show increased growth the first couple of years in the acidified plots, followed by decreased growth the last year. Similar patterns, though not significant, have been found in some of the other experiments. Chemical analyses of the foliage have revealed that the most likely explanation of the increased growth is increased N uptake. The decrease in growth observed in 1979 might be related to reduced availablity of Mg as the foliar concentration is close to values giving visual deficiency symptoms.

Short-term growth results from acidification experiments must be treated with caution. They indicate, however, that tree growth may be reasonably stable when the plant-soil system is stressed by acid rain. Another difficulty to be kept in mind is that part of the acidity of rain is due to nitric acid or nitrogen oxides, which means that the positive fertilizer effect of nitrogen may partly or fully compensate for any harmful effects.

Theoretically there might be cases where acidity caused by sulphur oxides is counteracted by fertilizer effects, since sulphur is an indispensable plant nutrient. However, deficiency in sulphur has never been observed in forest trees under natural conditions in Scandinavia, and considering the rather tight nutrient circulation in the forest ecosystem, it is not likely to occur except possibly on very extreme sites.

A number of possible effects of acid rain on biological processes in the forest soil has been considered by Tamm, (1976), Abrahamsen, (1980). Most forest soils have a considerable buffer capacity. Therefore, we may assume that the supply of acidity, measured either as hydrogen ions or as "strong acid" of industrial origin, cannot yet have affected the entire soil profile, except possibly in the immediate vicinity of emission sources. Still, effects may be found on processes occurring in the top-soil or on the surface of soil particles. Soil organisms, including roots, in the upper soil horizons may also be affected. Soil respiration, nitrogen

turnover which is intimately connected to organic matter decomposition in soil, nitrification, nitrogen fixation and nitrogen immobilization are some of the processes apparently affected by increasing soil acidity. There are a number of other biological processes which may be affected by a change in soil acidity or sulphur supply which have not yet been studied.

Several comparative and experimental investigations have yielded evidence in support of the theoretical assumption that acidified precipitation, like any other change in climate, will result in changes in the properties of soil. Influences from this changed chemical climate on soil conditions have been indicated through decreases in pH and base saturation as well as increased leaching. From the studies performed up to now, however, it is difficult to draw any definite conclusions on the time required for the reactions and their intensities. Many soils are far from the stable and mature stage, and it is a well-known fact that considerable changes due to factors other than acid precipitation may simultaneously be affecting the properties of the soil. The great variation in soil types and in their susceptibility to acid precipitaiton make detection even more difficult before the expected effects have become extensive.

The relative significance of strong acids and ssociated heavy metals found in heavily polluted areas has not been clearly established in erms of toxic effects on plants and soil organsms. The most serious consequence of regional cidification at currently observed levels may e the increased rate of leaching of major elements and trace metals from forest soils and vegtation. This is true for the forest ecosystem nd also has a bearing on the aquatic systems eceiving these effluents.

Aquatic Ecosystems

Freshwater bodies in many areas of northern rope and eastern North America, that today lie and adjacent to the areas where precipitation most acid, are threatened by the continued position and further expansion of acid precitation. Many of these bodies of fresh water e poorly buffered and vulnerable to acid ints. These ecosystems appear fated to suffer idification and loss of fish populations. Eally as serious as damage to fish are the less nspicuous effects of the acidification of esh water including changes occurring in communities of aquatic organisms such as microdecomsers, algae, aquatic macrophytes, zooplankton d zoobenthos.

ter chemistry

The composition of the lakes which are dissed in connection with acidification depends on three principal sources of chemical components - atmospheric inputs of sea-water salts, atmospheric inputs of acid precipitation and terrestrial inputs of chemical-weathering products.

Unpolluted, soft water lakes are generally dilute solutions of Ca and Mg bicarbonate. The bicarbonate system constitutes the main buffering system in the water. Lakes in regions underlain by highly resistant, carbonate-poor rocks have lower buffer capacities, and are vulnerable to the input of acid precipitation. A major number of the lakes in Scandinavia fall within this category, especially above the postglacial marine limit, where the bedrock over large areas is covered by only thin glacial deposits. A continuous supply of acid substances to lakes and streams eventually leads to the depletion and loss of the normal buffer system. The pH falls to below 5.0, and sulphate becomes the major anion. Such lakes have only minimal capacity to neuralize additional inputs of acid; and new inputs of acid cause sharp drops in pH, Wright and Gjessing, (1976), Henriksen, (1980).

Acid precipitation also causes other changes in lake water chemistry as well. The acidic, high sulphate lakes also have high aluminum concentrations. Since precipitation contains very little Al, the Al in the lake water must come from the drainage basins. That has been shown to be the case in investigations conducted on 9 small drainage basins in southern Norway. It has been shown that loss of calcium, magnesium and aluminum from the basins is partly due to natural weathering processes, but a major fraction probably results from the massive inputs of acid precipitation. In granitic basins there is approximately equivalence between net H^+ input and Ca + Mg + Al output.

The deposition of acid precipitation occurs episodically. Acid precipitation generally causes two seasons of increased acidity in streams and rivers - the fall, a season of frequent rain, and the spring, when pollutants stored in the snowpack are released in the first part of snowmelt. Laboratory and field studies of polluted snow have shown that the first fractions of meltwater due to concentration effects within the snowpack contain higher concentrations of pollutants than the bulk snow. The first 30 per cent of the meltwater contains up to 70 - 80 per cent of the total amount of H^+, NO_3^- and SO_4^{2-}.

The episodic deposition of air pollutants and a certain temporary accumulation of sulphate in the summer results in major short-term increases in the acidity of lakes and rivers and these changes are most frequent in the fall and spring. From a biological point of view these periods are often critical because they are spawning and hatching seasons for many aquatic organisms.

Regional surveys

A large number of surveys have been conducted to give a picture of the acidification of Scandinavian lakes and rivers. A systematic survey of 155 lakes in southern Norway was conducted in October 1974, and repeated every year since, on varying number of lakes.

Excess sulphate is sulphate that does not come from sea water salts. Although in some lakes, this excess sulphate comes from a terrestrial source in the drainage basin, the regularity of a SE-NW gradient most probably is due to chronic inputs of anthropogenic sulphur through precipitation and dry deposition. Indeed, the distribution of excess sulphate in lakes is remarkably similar to the weighted average concentration of excess sulphate measured in precipitation over southern Norway.

The pH levels in the lakes can be largely explained by inputs of acid precipitation in the SE-NW gradient superimposed upon the variations in buffer capacities due to the geology of the drainage basin.

Aquatic organisms

Acid stress on life in rivers and lakes has effects on all stages in the food chain. Primary producers communities, like phytoplankton, are simplified by a reduction in the number of species. The composition of a community may alter with a shift to more acid-tolerant species.

Macrophytic vegetation has been observed to change in acidified lakes. In some lakes Sphagnum occurs in dense mats, and epiphytes are well developed. Generally, the vegetation in acidified lakes is poor in species.

The same tendency of an acid-tolerant shift is observed in diatom communities in 7 locations in southern Norway described in 1949 and revisited in 1975. There was an increase in the proportion of species which prefer or require acid water.

In some acidified lakes, an increased accumulation of organic bottom sediment has been observed, indicating a reduced rate of decomposition. There are strong suggestions that microbial decomposition is reduced in acid water and that slow-acting fungi take over. This will influence the nutrient exchange with the lake sediments.

In the invertebrate freshwater fauna the same trends are observed: a reduced number of species and a total reduction in biomass in the acid locations. Experiments on the tolerance of certain crustaceans which are important as fish food (*Gammarus lacustris* and *Lepidurus arcticus*) have shown a direct mortality of eggs at pH 5.5 or lower. There are also delays in the development from stage to stage of surviving animals. Exposure below pH 5.5 will kill a majorit of adult individuals even after a short time, 1 - 2 days. In Norwegian lakes, snails are rare a pH below 5.8 and disappear below 5.2.

In spite of the strong effects on fish food organisms, the indications are that changes in fish food supply play a small role in the elimination of fish from acid rivers and lakes. Instead, lack of recruitment seems to be the domina factor. The tolerance against acid water is lowest in newly hatched larvae. This fact makes th spring flood a particularly critical time for th fish population.

The physiological mechanism or mechanisms responsible for fish death in acid water are not fully understood, but it has been well established that acid stress is accompanied by a failure in salt regulation within the fish body. Metabolism and osmotic cell regulation seem to be affected. It is also quite clear that the salt uptake and loss is influenced by the ion content of the water. Elevated concentrations of aluminum, manganese, zinc, cadmium, lead, copper, and nickel have frequently been observed in acidified lakes. The abnormally high concentrations are apparently due to direct deposition with precipitation as well as to increase release (solubility) from the sediments. These metals may represent a major physiological stre for various aquatic organisms.

Fish population statistics from nearly 1000 lakes in southern Norway show that when both pH is low (e.g. pH 4.7) and salinity is low (e.g. < 10 µS cm) almost all lakes are empty of fish. At higher salinity (< 20µS/cm) several lakes have sparce populations and a few even good.

The recent acidification of freshwater in parts of Europe and eastern North-America has profound impacts on aquatic life. It can be stated with reliability that all trophic levels are affected. Of immediate concern to the peop living in the acidified regions is the major decline in fish populations. In the four souther most counties in Norway more than half of the fish populations have been lost during the 1940-1980 period. Today, lakes in more than 13,000 km^2 of south Norway are practically devoid of fish, and in an additional 20,000 km^2 the fish stocks are reduced. Continued water acidification is a threat to hundreds of lakes still harbouring valuable fish populations (Muniz and Leivestad, 1980).

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The Impact of Acidic Precipitation and Heavy Metals on Soils in Relation to Forest Ecosystems[1]

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Abstract: Normal terrestrial cycling of metals in eastern North America and the Pacific Coast states has been altered by the increasing acidity of precipitation, and associated heavy metal deposition and mobilization. Pb and chemically similar metals are accumulating in soils. Al, Ca, K, Mg, and Mn are being leached from soils. The mobilities of Fe, Zn, and P vary with site characteristics. Biological recycling of nutrients by decomposition and uptake is impeded by lowered pH and elevated levels of toxic metals in soils. Increased leaching of nutrients in the O and A horizons, caused by increased H^+ inputs, decreases percent base saturation and thus decreases nutrient pools for shallow rooted plants, especially seedlings. Deeper rooted plants are subjected to elevated, potentially toxic, concentrations of dissolved metals (e.g., Al and Mn).

In many contemporary forest ecosystems, nutrient availability is barely adequate for sustained yield with bole harvesting techniques. Our work indicates that nutrient pools are diminishing in the northeastern United States, suggesting that decreases in forest productivity will occur.

Large areas of the northern hemisphere are receiving precipitation which is more acidic than would be predicted by equilibration of rain and atmospheric CO_2:

$$H_2O_{aq} + CO_{2g} = H_2CO_{3aq} \qquad K \cong 10^{-1.5}$$

$$H_2CO_{3aq} = H^+_{aq} + HCO^-_{3aq} \qquad K \cong 10^{-6.3}$$

$$HCO^-_{3aq} = H^+_{aq} + CO^=_{3aq} \qquad K \cong 10^{-10.3}$$

The resulting pH should be about 5.6. This may be modified by the hydrolysis of particulates or the addition of naturally occurring organic and inorganic acids. Precipitation pH's in the U.S., prior to pollution of the atmosphere, probably ranged up to about 8.2 (corresponding to semi-arid to arid regions where $CaCO_3$ dust, or its equivalent, dominates the rain chemistry).

$$CaCO_{3xl} + H^+_{aq} = Ca^{++}_{aq} + HCO^-_{3aq} \qquad K \cong 10^2$$

Atmospheric concentrations of CO_2 should result in a pH of about 8.2. In eastern North America, where vegetation cover minimizes particulate injection into the atmosphere, unpolluted precipitation would probably have a pH of about 5.6. Associated with the precipitation are numerous metals and plant nutrients (e.g., Na, K, Ca, Mg, NO_3^-, NH_4^+, $H_2PO_4^-$, Pb, Zn, etc.).

Precipitation (wet and dry) is one of three inputs into the nutrient budgets for forest ecosystems. The others are chemical weathering of inorganic soil and nutrient cycling within the canopy/root space. Both are closely linked to precipitation chemistry.

Simply put, from a nutritional point of view

Input - Output = Net accumulation of organic material.

Output consists of leaching to groundwater (bel

[1]Presented at the Symposium on Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, June 22-27, 1980, Riverside, California, U.S.A.

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e root zone), injection of particulates into the mosphere, volatilization of certain elements, d loss of particulates "downstream", including rvesting. If the mass balance (above) is posi- ve for all limiting nutrients, growth and accu- lation of organic matter will occur as living omass or as soil organic matter. If the mass lance is negative, growth can occur only so long the decreasing reservoirs of organic matter and rients from precipitation and chemical weather- ; can supply necessary nutrients; organic matter st decrease. The amount of organic material on forest floor and contained in the rooting zone the mineral soil is generally of the same order magnitude or larger than the organic material tained in the above ground biomass. Removal of s biomass disrupts the recycling of nutrients. tinued growth of new biomass must occur from reservoir within the soil, forest floor, and m precipitation.

A forest ecosystem can subsist on nutrients de- ered solely by precipitation, both wet and dry t et al. 1974). However, it is doubtful that s precipitation-based forest ecosystem could be vested periodically and still have sustained wth. If there are changes in the chemistry of cipitation, specific inputs/outputs of the est nutrient budget may be altered so as to ect both sustained growth yields and net orga- matter accumulation.

Many forest ecosystems are not forced to sub- t on atmospheric inputs alone. They receive itional primary inputs of nutrients from chemi- weathering of mineral matter. However, in laciated areas of the eastern U.S. where chemi- weathering dominates over mechanical weather- or in glaciated granitic (nutrient poor) ter- ns characteristic of large areas of eastern th America, nutrient pools are largely con- ned within the organic litter of the forest or. Thus, these areas are the most vulnerable depletion of nutrient pools due to acidic pre- itation.

Nutrient availability is commonly classified as icient (where addition of the limiting nutrient its a positive response), adequate (where ad- ion of a nutrient does not elicit a response), excessive (where addition of the nutrient eli- a negative response). This paper investigates of the consequences of increased acidity and l availability, associated with acidic precipi- on to nutrient availability (and thus to for- productivity). Excellent reviews of potential lems are given by Voigt (1979) and in Hutchin- and Havas (1980).

EFFECTS OF DECREASED pH

lthough early precipitation chemistry is sparse North America, Cogbill and Likens (1974) con- cted 3 pH isopleth maps spanning 1952 to 1972 h suggested increasing acidity for precipita- in the eastern U.S. and a broadening of the

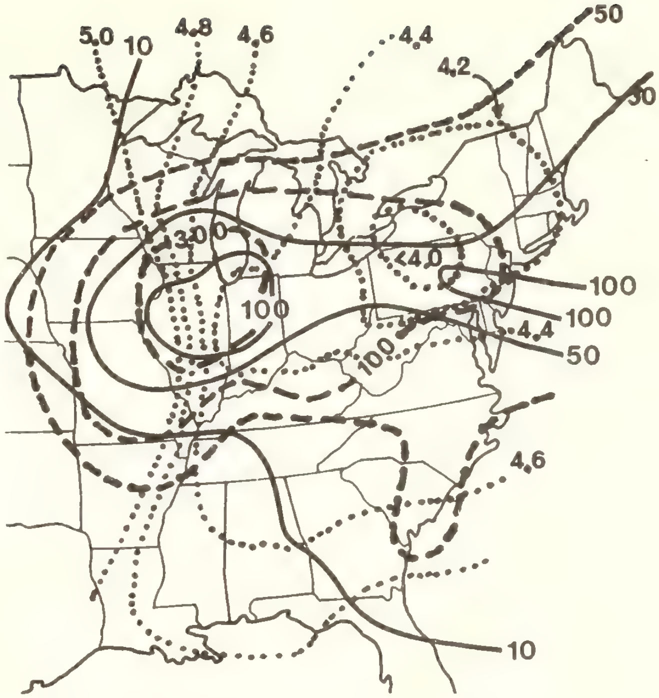


Figure 1--Generalized pH (dotted) (NADP 1979, 1980; CANSAP 1979), Pb (solid) and Zn (dashed) isopleths (Davis and Galloway 1980) for eastern U.S. precipitation. Fluxes are g/h/mo.

area receiving acidified precipitation. Recent data (NADP 1979; NADP 1980 a,b; CANSAP 1980) shows a continued decrease in the pH to average values of less than 4.0 for the "bull's eye"; the eastern half of the U.S. and the eastern half of southern Canada is receiving precipitation with a pH less than 5.0 (fig. 1).

Most of the lowering of the pH of precipitation from "normal" to present levels occurred over the last 40 years. In North America, there are no long term regional studies of the acidification of soils showing trends related to regional pH gradients. Linzon and Temple (1980) (in Ontario) found acidification of soils over a 16 year observation period. Many studies have been made of soil acidification and nutrient status in areas heavily affected by point sources.

Expected changes in the inorganic aspects of soil chemistry associated with acidification include desorption of metals from organic and inorganic cation exchange surfaces, increased solution of "mineral" colloids and crystalline minerals, and changes in metal speciation and thus biological availability.

Desorption of metals

Regardless of the nature of the substrate, ion exchange (for a monovalent ion) may be represented as

$$RX + H^+_{aq} = HX + R^+_{aq}$$

where X is an exchange site, R^+ is any monovalent metal, H^+ is a proton, and aq refers to an aqueous specie. This reaction can be forced in either direction by changing H^+ or R^+ activities.

Pre-pollution precipitation in eastern North America entered the soil with a pH probably in the range 5.5 to 6.0. Microbial activity in the organic litter produces molecular CO_2 which can reduce the pH considerably (as low as 4.5 to 5.0). The production of various organic weak acids (e.g. fulvic and humic) may depress the pH further to 4.0 to 4.5. To maintain electrical neutrality in these solutions to offset the H^+ production, either anions must be gained (HCO_3^- activity is reduced by the lowering of pH; organic anions may be produced) or cations must be lost from the solution. This is most effectively accomplished in the litter and at root surfaces where H^+ is exchanged for percolating cations. Thus nutrients are gained by the soil.

If the precipitation has a pH of 4.0 due to the strong acids H_2SO_4 and HNO_3, the exchange reaction is forced strongly to the right, stripping cations (particularly Ca and Mg) from the litter, reducing percent of base saturation. Continued production of CO_2, organic acids, by microbial activity assures that the cations are lost from the system.

No long term studies of soils exist to demonstrate the switch from accumulation to loss of cationic nutrients as a result of low pH precipitation. Indirect evidence for the switch consists of long term changes in surface water quality such as conductivity (Malmer 1976 [in Sweden]), alkali and alkali earth concentrations (Malmer 1976), and the commonly observed relationship between non-dystrophic low pH waters and elevated Ca, Mg, Al, Mn, and other metals. Ulrich (1980) and Linzon and Temple (1980) have shown loss of base saturation in soils over 8 and 16 years, respectively. Abundant experimental evidence (e.g., Hutchinson 1980; Abrahamsen and Stuanes 1980) and studies of soils adjacent to large point source emitters of SO_x and NO_x suggest what long term results might look like. Ca, Mg, K, Zn, Cd, and Mn are readily leached from litter. However, the pH levels employed for experimental work are commonly well below what we might expect on a regional basis. Processes operating at a pH <4.0 may not be effective even over long periods of time at pH>5.0.

A transect of "equivalent" soil sites across a regional pH gradient (fig. 2), in effect, is a time study of the effects of low pH precipitation. Table 1 indicates a progressive decrease in $\frac{CaO}{Al_2O_3}$ and $\frac{MnO}{Al_2O_3}$ in a southwesterly direction, toward lower pH precipitation. We interpret this as a preferential leaching (desorption) of Ca and Mn from the litter.

Organic matter in lake sediment is derived from both the watershed and the lake water column. Organic-rich lake sediments in acidified lakes in New England (Williams 1980) are depleted of CaO,

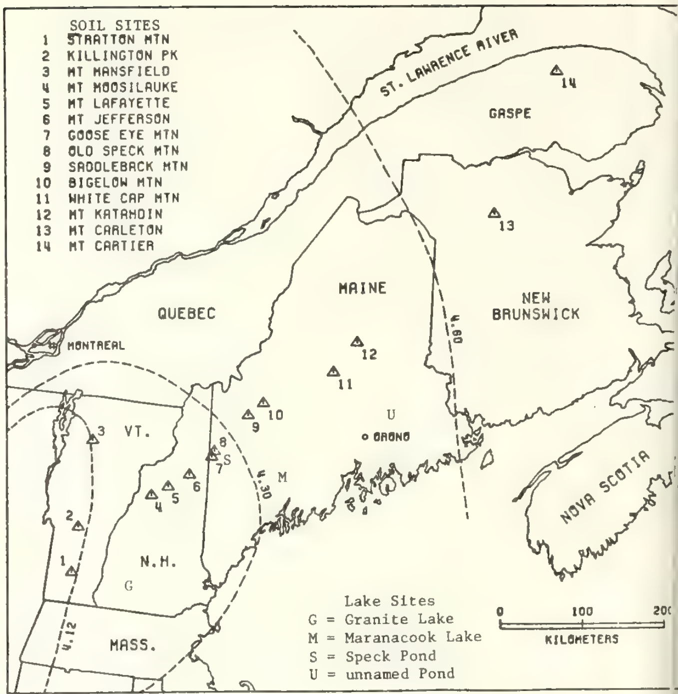


Figure 2--Location of soil localities reported in Table 1 (Hanson 1980) and location of lakes for which Figure 4 is developed. pH isopleths are for 1975/6 (Likens et al. 1979).

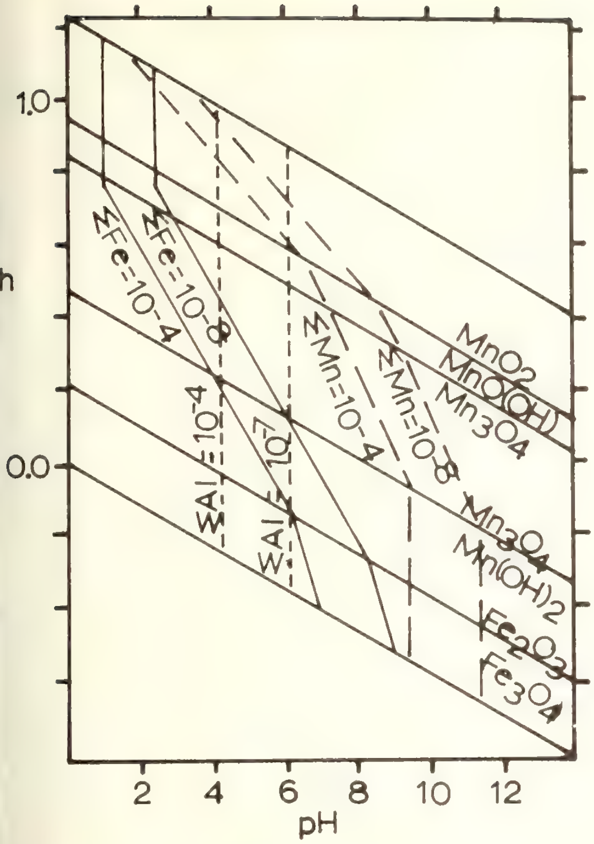
also suggesting that forest litter is being leached before it is transported to the lake and/or that leaching continues while the sediment is in contact with acidic lake water.

Solution of Metals from Minerals or Colloids

The release of cations from minerals due to acidic soil water weathering may be represented

Table 1--Chemistry of forest litter from high altitude fir forests. Sample sites are shown on figure 2. Note: Site 6 is anomalous for all parameters. Site 12 had abundant admixed mineral soil and the bedrock is very low in MnO. Details of collection and analysis are in Hanson (1980).

Site	$\frac{CaO}{Al_2O_3}$	$\frac{MnO}{Al_2O_3}$	Pb(ppm)	Zn(pp
1	7.62	0.21	189	72
2	4.08	0.09	204	59
3	5.44	0.16	187	61
4	7.43	0.25	171	77
5	5.36	0.34	178	84
6	11.87	0.63	85	81
7	3.91	0.32	129	78
8	9.21	0.63	136	83
9	12.36	0.45	137	86
10	10.22	0.45	112	78
11	20.71	1.00	140	86
12	10.22	0.32	86	81
13	15.29	1.06	118	94
14	18.68	0.99	63	68



gure 3--Eh-pH diagram for the system Al-Fe-Mn-H_2O at 25°C and 1 atmosphere. Solubility in es/l.

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$$R^{+n}X_{xl} + nH^{+}_{aq} = R^{+n}_{aq} + H^{+}_{n}X_{xl}$$

re R is a metal, n is the valence of the metal, is the stoichiometric formula for the mineral nus R), H^+ is a proton, and aq refers to aqueous cies. Reactions of this type are forced by vated H^+ levels. Mn^{+2}-, Fe^{+2}-, Fe^{+3}-, and Al^{+3}-ring minerals are somewhat unique in that the pective metal's mobility is a function of $[H^+]^2$ even $[H^+]^3$ activity and the transition from geo-mical immobility to mobility under oxidizing ditions takes place at a pH between 4 and 6 g. 3).

Increased mobilization of Al from inorganic ls has been documented by Cronan and Schofield 79). Both experimental and field studies le 1) suggest that Mn is leached from upper els of soils. Data are sparse but indicate acidic non-dystrophic surface waters have vated Mn levels. Al and Mn have toxic effects plants via root effects, and on aquatic animals. although leached somewhat by acidic percolating tions (Cronan and Schofield 1979), is relatively ched in the litter in leaching experiments and he field (Hanson 1980). Downstream reduction oncentration of metals may be accomplished by tion (Ca, Mg, K), precipitation (Fe, Al, Mn), adsorption (P, Zn).

Overall, acidic precipitation accelerates podsolization, expanding depths of upper soil horizons, and depleting the nutrient pool in the upper soil.

Changes in Speciation of Dissolved Metals

Biological uptake of nutrients and toxicants is via molecular diffusion through semi-permeable membranes which are somewhat specific to the species involved. Biological response is highly specific to the dissolved form ("biological availability") of the element.

Decreasing pH affects speciation in two ways. Elements which complex with OH groups will be preferentially partitioned into a less hydroxylated form. For example:

$$Al^{+++}_{aq} + OH^{-}_{aq} = Al(OH)^{++}_{aq} \qquad K = \frac{Al(OH)^{++}}{(Al^{+++})(OH^{-})}$$

Lowered pH also results in protonation of weak acid radicals (e.g. HCO_3^-, fulvic$^-$, humic$^-$) causing a decrease in ligands for the cation of interest. For example:

$$HCO^{-}_{3aq} + H^{+}_{aq} = H_2CO_{3aq} \qquad K = \frac{H_2CO_3}{(HCO_3^-)(H^+)}$$

Because toxicity is generally greater for the uncomplexed metal (Hg is an exception), acidification of soil waters should result in greater direct toxicity to roots and micro-organisms or foliage after uptake, and on "downstream" ecosystems.

INCREASING TRACE METAL MOBILITY/AVAILABILITY

Trace metal levels, particularly heavy metals, are intimately affected by acidic precipitation in that their flux to the forest ecosystem is greatly increased over pre-pollution values and their mobility is in some cases greatly altered.

Historic data to evaluate the changing atmospheric flux of heavy metals in North America is absent. Changes in fluxes with time in remote regions have been evaluated from snow/ice cores (Cragin et al. 1975). Anthropogenic emission rates may be compared with natural emission rates to obtain an estimated percentage increase or mobilization factor. For Cd, Mn, Pb, and Zn the factors are 13, 0.48, 180, and 13 respectively. However, these factors may not relate closely to deposition values (Galloway et al. 1980), because of spatially non-homogeneous emission, dispersion, and deposition.

Limits on pre-pollution metal concentrations in precipitation may be established using modern data for precipitation chemistry from modern remote sites. Metal levels for eastern North American must have been between the remote (Antarctica)

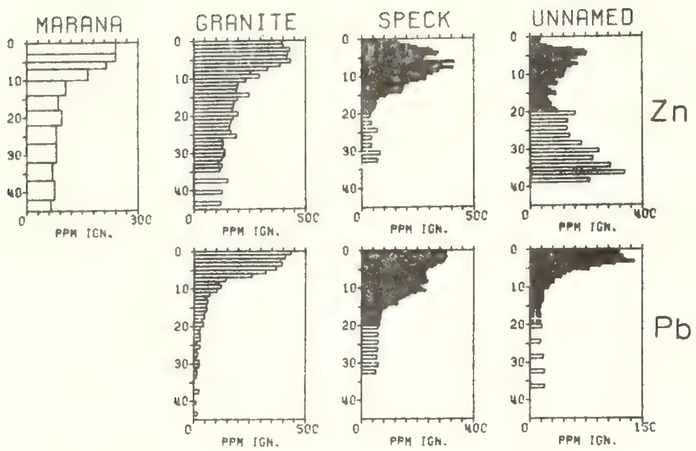

Figure 4--Pb and Zn profiles for sediment from a circum-neutral (Maranacook), slightly acidic (pH, 5-6) (Granite), and acidic (pH<5) (Speck) lake with surface inlets and outlets and an acidic (pH <5) kettle pond ("unnamed" Pond). Ponds are located on Figure 2.

and North Atlantic values. (We know that Greenland [Cragin et al. 1975] has been receiving polluted precipitation for approximately 200 years.) Modern deposition rates for Pb and Zn are roughly known (fig. 1). However, our poor knowledge of pre-pollution deposition rates doesn't permit a good assessment of the increases that have occurred for eastern North America.

Lake sediments record changes in atmospheric deposition but normally not in a straight forward manner because of watershed effects, sediment focusing, and diagenesis (Norton et al. 1980). Figure 4 (unnamed Pond profile) suggests a minimum of an 800% and 200% increase for the deposition rate for Pb and Zn, respectively, over the last 100 years. These figures assume that the background levels (below 15-30 cm, depending on the lake) are due to atmospheric deposition. However, most of the background concentrations are probably bedrock contributions. Based on increases for Pb and Zn concentrations in sediments from remote lakes in New England, we estimate that atmospheric deposition rates in New England have increased at least by a factor of 30X. Pre-pollution concentrations of heavy metals in soils are unknown. Short term studies (Siccama et al. 1980) of heavy metals in soils indicate that concentrations are increasing with time. Our data (fig. 2, Table 1) shows a strong relationship between the pH gradient and Pb accumulation, consistent with the Pb deposition gradient (fig. 1). These concentrations are of concern with respect to toxic effects for soil microbial activity and nutrient cycling. High Pb concentrations in litter are also considered as possible controls on the biological availability of phosphorus in soils (Cox and Raisons 1972).

However, even with elevated deposition rates it appears that Zn (and other elements with similar chemical behavior) is not accumulating in forest litter (Table 1) although biologically available B-horizon accumulation occurs (Conrad, pers comm.). This appears to be related to increased leaching of Zn from litter due to decreased pH of precipitation; lake sediments from New England exhibit similar behavior (fig. 4). Acidified watersheds have lake sediments being deposited which have less Zn than sediments deposited prio to their acidification.

SUMMARY

Acidic precipitation, experimentally and empirically, accelerates podsolization and deplete nutrient pools in forest litter and shallow inorganic soils. Some heavy metals (e.g. Pb) accumulate to concentrations which may impede biologic soil processes and immobilize phosphorus. Other metals are mobilized (Al, Mn, Zn) and may affect ecosystems "downstream". Paleolimnological and soils data from New England indicate that acidification of drainage basins (including soils) ha occurred and nutrient depletion is underway.

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Impact of Heavy Metals on Terrestrial and Aquatic Ecosystems[1]

Tom C. Hutchinson[2]

Abstract: The high toxicity of many metals and metalloids to a wide range of biota, coupled with their long residence times in the soils, in sediments and in the oceans has led to real concern about their role in environmental deterioration. Residence times in watersheds are commonly measured in hundreds of years, while residence of metals in air is rarely as long as several days. Overall industrial activity and transportation leads to widespread metal dispersion. Major elevations in many metals occur around mines and smelters and for lead especially, alongside highways. Coal-burning and applications of fertilisers and pesticides add metals to agricultural soils and to natural ecosystems. The surface organic layers of both soils and sediments act as adsorption and exchange sites so that major accumulations may occur. Yet, this shallow organic layer is the critical site for many microbial activities, including those essential for nutrient cycling, nitrogen fixation and for pathogens. Genetic and physiological tolerances are shown in a wide array of different organisms which have survived in metal-stressed habitats. Most recently, acid precipitation has mobilised Al, Mn, Fe and Zn from the soil and sediment. These are now producing particular stresses for aquatic biota.

The considerable toxicity of many metals to biota is well known e.g. lead, mercury, cadmium, arsenic. The quantities mined and smelted for innumerable uses continues to rise each year. It is apparent that both natural and man-made ecosystems are the recipients of increasing quantities of these elements and that we have to be continuously vigilant to ensure that we do not either poison ourselves, our fellow biota, or ou agricultural and natural ecosystems. Major huma poisonings have occurred such as that by mercury in Japan and in Iraq, and that of cadmium in Japan. The beer-deaths in Birmingham, England a the turn of the century were also believed to be metal-related, being variously ascribed to arsen and/or selenium. Concern has also been expresse about not only the potential for food chain contamination leading to man but also to direct aer inputs to man via the respiratory tract. Lead from automobile emissions where it is used as an anti-knock in gasoline, and from primary and secondary smelters, as well as many other smelte

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ɜmitted metals such as arsenic, copper, nickel, ɀinc, cadmium, antimony and selenium, all have ›otentially harmful consequences due to their ›ersistence in the body, and their ability to .nterfere with specific enzyme systems. It ;hould also be noted that many instances are :nown of synergistic and antagonistic interactions ›etween metals, both in aquatic and terrestrial ystems and in the human body. Notable amongst .hese are the ameliorative effects of selenium .nd arsenic on both mercury and cadmium toxicity n mammals and the recently described synergistic ffects of ozone on cadmium and nickel toxicity n certain crop plants, e.g. Parizek 1978, evander 1977, Groth and others 1973, Czuba and rmrod 1974. Nickel and copper synergisms have een described for a variety of biota, including reshwater unicellular algae, floating aquatic lants, and tree seedlings, Hutchinson 1973, utchinson and Stokes 1975, Hutchinson and Czyrska 972, and Hutchinson and Whitby 1974.

Despite what sometimes seems to be a gloomy icture with respect to metal accumulations in ıe environment, it ought to be borne in mind ıat concentration of airborne particulates in rban and industrial areas of Europe and North nerica have often been much worse in the past. ›hen and Ruston (1925) reported very high ·rsenic levels in the air of Leeds, England in ›02-1910 due to coal burning, while the overall ɜvels of SO_2 and acidic aerosols were much .gher than presently occur.

Residence Times and Watershed Loss

Rather little attention has been paid to the :sidence times of metals in components of the losphere. The strong retention of metals on e organic surface layers of the soil and of the ɛdiments is of great importance, in that it ‹uses long residence times as well as in allow- ;g accumulation of metals to potentially toxic ‹ncentrations. Since it is precisely in these ɛrface zones that the major populations of ɪcrobes are located, and where the essential ɪocesses take place of decomposition of organic ɪtter, of nitrogen fixation and of elemental ɛcling etc. Thus, the persistence and ɑcumulations of toxic elements is of real ɕncern. Litter in urban areas contains elevated lad concentrations.

The retention of the metals themselves is an e:change process, with the elements behaving in a:easonably predictive way, based on such p›perties as ionic radius and electronegativity. A.d leaching can cause a downward movement of hıvy metals through the profile, so that they m enter ground water or watershed streams. (g. Abrahamsen, Stuanes and Bjor 1979, Cronan a Schofield 1979, Hutchinson 1980, Bacon and M.s 1979.) Both rock surfaces and soils can c.tribute and such clay mineral constituents as aluminium, manganese, zinc and ferric iron enter drainage water in this way. Sediments can similarly lose these same elements to the water bodies of lakes under acidifying conditions (Schindler and others 1980). The damaging effect of the resultant aluminium concentrations to fish have been described by various authors, including Schofield 1976, Baker and Schofield 1980, at levels as low as 0.1-0.2 mg/l. Increased transport of aluminium into aquatic systems can also affect phosphorus availability (Cronan and Schofield 1979).

The residence time of metals in the air is always very much shorter than that in soil, water, sediments or oceans. This is illustrated by Table 1, which emphasises the rather larger residence time of lead in air than that of a wide range of other metals. This partly explains the elevations of lead noted at remote locations, such as in the arctic, in glacial ice in Greenland and at mountain tops in California (see National Academy of Sciences Lead Review 1980). It is also a function of particulate size and partial vapour pressure.

Table 1. Residence times[1] of metals in the atmosphere at La Jolla and Ensenada, from Hodge, Johnson and Goldberg, 1978.

	days	
	La Jolla	Ensenada
Pb	7	8
Cd	0.7	0.5
Ag	0.2	0.1
Zn	0.4	0.3
Cu	0.5	1
Ni	3	0.8
Co	1.2	0.2
Fe	1.0	0.4
Mn	0.8	0.2
Cr	0.8	0.4
V		0.6
Al	1.0	0.2
Pb 210	5	---
Pb 239 + 240	1	---

[1]Standing crop of metals on particulates in 1,000 m X 1 cm^2 column of air (filter data--Table 1) divided by the flux to 1 cm^2 of ground surface (bucket data --Table 2). Filter data averaged over period during which buckets exposed. Filter concentrations of Co, Fe, Mn, Cr and Al have been multiplied by 2 in order to account for the discrimination against large particles by the Hi-Vol sampler.

The contrasting data for watershed soils are illustrated by Table 2, taken from Bowen 1975, and from which it is apparent that soil-watershed residence times are measured in hundreds of years.

Table 2. Inputs and outputs in mg X/m^2 yr, and residence times in years, for nine elements in soils of the Upper Thames basin.

X	Rain input	Fertilizer input	Rock input	Drainage output	Cropping output	Residence time/ years
As	1.6	0.3	0.014	0.04	0.2	2000
Cd	0.5	0.6	0.0004	0.5	0.2	280
Cr	3.8	3	0.06	0.02	0.08	6300
Cu	11	0.8	0.04	1	5	860
Hg	0.08	0.002	0.0004	0.008	0.005	920
Ni	5	0.9	0.1	1	1	2300
Pb	37	0.8	0.13	0.4	1	400 - 3000
Sc	0.44	0.03	0.003	<2	0.07	<2500
Zn	43	5	0.12	1	58	2100

Clearly the potential for accumulation to toxic levels is much greater. The excess of lead and chromium in input over output is a feature of systems subjected to industrial deposition. The volatilization of some of these heavy metals from the foliage of vegetation e.g. zinc, mercury, and selenium (Beauford and others 1975) may re-mobilise small quantities of these metals and increase atmospheric residence times but it will not influence loss into drainage waters. Allen and Steinnes (1979) determined the regional distribution of lead, zinc, cadmium, copper, arsenic, antimony and selenium in Norwegian surface soils, utilising 500 humus samples. Lead levels were 10-fold higher in the south than in the arctic areas and also higher along the coast than inland. Cadmium, arsenic, antimony and selenium showed a similar north-south trend. All of these elements are highly volatile, low boiling point components of the atmospheric load from industrial and urban centres.

Residence times in soil water are affected to a great extent by pore size. The water in the large pores infiltrates into lower layers and air enters again behind it. The residence time in these pores is not more than hours. Meanwhile, the water in the narrow pores is displaced only centimetres or millimetres. An example is shown in Table 3 from the work of Frissel (1978), with residence times as high as 5000 years. The implications for ground water contamination are apparent.

Targets for H^+ and Heavy Metals

I should like to emphasize that one very useful way of considering the potential threats to ecosystems is through a consideration of targets in the ecosystem. Clearly, all surface interfaces fall into this category. Surfaces present areas of potential accumulation or residence. In terrestrial ecosystems, including agricultural ones, the surface of the leaf is one such interface. Higher plants are covered by a rather impermeable waxy cuticle, which reduces gas and water flow to a minimum but is perforated by numerous stomata, often on the underside of the leaf especially. While particulates can accumulate on such a surface, they are also rather easily washed off by rain or blown off by wind. Frequently, however, small particles can be incorporated into the cuticle or enter the stomata. The leaf surface of many plants also are covered by numerous fine branched hairs or glands. These can act as traps for particulates so that very dirty leaf surfaces can occur in areas of high dustfall. Nevertheless, the directly toxic effect of particulate metal constituents are limited as they are kept away from metabolically active sites.

In the mosses, liverworts and lichens, the cuticle is effectively absent. The exposed cell wall surface is at the air interface and it consists of charged sites, which can exchange both cations and anions. The metals are selectively exchanged onto this surface and are held there. Large accumulations can take place. Lichens in polluted regions attest to this, as do mosses (e.g. Rühling and Tyler 1970). The use of Sphagnum moss bags as air monitors is based on this cation exchange capacity. The special sensitivity of many lichens to air pollutants is due to the ready entry of the pollutant to metabolically active sites.

Soil Surface Layers as Target Areas at Risk

The surface of the soil as a critical site for accumulation of airborne metallic contaminants has already been referred to here. It is in this upper few centimetres of the soil that nutrient uptake into plant roots takes place and in which new root hairs are developed. Seeds germinate in this layer amongst the forest litter and seedlings establish there. The microbial sequences essenti

Table 3. Residence times of water in the saturated zone of the soil.

Discharge per year (mm)	System and pathways	Estimated residence time depending on the place of infiltration and on porosity of the soil or rock	Watershed
A. 250 mm	About constant slow discharge 17 partly 12	100-500 years	Merkenfritzbach (Federal Republic of Germany, Land Hessen, Main area) 1600 ha
350 mm	slow discharge 12	1—500 years	
160 mm	fast discharge 10 partly 12	1 day—10 years	
B. 150 mm	(12, 17)	10—1000 years	Okkenbroek (The Netherlands, IJssel area) 443 ha
100 mm	(12)	1 day—10 years	
50 mm	(4, 10)	1 hour—1 day	

for effective litter decomposition take place, in this zone pathogens strive to infect seedlings or root systems, and the mycorrhizal fungi essential for effective nutrition of many forest trees, especially in the boreal forest, develop here. The rhizobial bacteria which act as nitrogen fixers in legumes and the actinomycetes and blue-greens which fulfill this role in other shrubs and grasses also have to infect roots in these upper few centimetres of the soil. Yet, onto this surface is being deposited increasing loads of toxic heavy metals, of acidifying substances and also of gaseous pollutants. The threat to the safe functioning of such ecosystems and to the well-being of man are focused on this zone. Indeed, we can consider that the reduction or elimination of just a few key processes could put the whole system at risk. The enzyme aryl sulphatase which produces the plant-available sulphate from the non-available organic sulphur in soils is one such step, and it is known that soil-extracted aryl sulphatases are susceptible to a wide range of heavy metals including aluminium. The ability of rhizobial bacterial to infect legume roots is also known to be acid sensitive and heavy metal susceptible. The conditions for seedling establishment might be affected if the atmospheric inputs of wet and dry deposition were to acidify surface soils so as to favour fungi at the expense of bacteria.

The threat to litter decomposition may be a long time in developing in most areas but in those where intense heavy metal accumulations have occurred from smelter emissions, examples of this have already been demonstrated. In both the remnant forest in the major Sudbury smelting area, where nickel and copper concentrations have reached up to 2000 ppm in the past and in the New Lead Belt of Missouri, where lead, zinc, cadmium and copper are now high, abnormal accumulations of litter on the forest are reported (Freedman and Hutchinson 1980, Watson and others 1976). At the zinc smelter of Palmerton in Pennsylvania, Strojan (1978) reported reduced decomposition of the foliage of a number of species and ascribed it to elevated zinc and cadmium concentrations.

The reports have also included detrimental effects on a number of soil enzyme activities, on overall microbial respiratory activity and on micro-arthropod and earthworm action. Indeed, many reports are now available which show sensitivity of earthworms to heavy metal accumulations.

Sediments as Sites of Risk

It should be noted that a rather similar but parallel case can be made for effects on surface sediments. Again, in this zone, much of the microbial activity takes place, the aquatic plants have to root, the benthic organisms live and reproduce and the important gas exchanges take place with the water column. This is the zone of deposition of the dead planktonic organisms, of incoming particulate matter and of pollutant material equally. The sediments are often highly organic and have a large cation exchange capacity. Toxic levels can develop (mercury in polluted sediments of the Detroit River and Lake St. Clair), and benthic-feeding fish, clams, crayfish etc. come in contact with pesticides, PCB's and heavy metals which have been initially transported by air. The methylation transformation which creates organic mercury compounds nine to ten times more toxic than inorganic equivalents take place here in the sediment surface layers.

Reproduction: crucial steps at risk

A number of essential sequential steps can be identified, the interference with which places the whole reproductive process at risk. These include a) the health of pollinators, especially the insects essential for those plants with specialised mechanisms and appropriate floral guides, trip mechanisms, nectar production, pollen positioning etc., b) the ability of the pollen to germinate successfully on the stigma and to then successfully produce a pollen tube which can reach the unfertilised ovules c) the ability of sperm to successfully reach and fertilise the egg d) the ability of plants and animals to successfully disperse their progeny to suitable new habitats.

Interestingly, it is known that steps a-c can all be affected by elevated levels of heavy metals. For example, bees are known to be very susceptible to airborne arsenic. In the region of the Novatny power station in Czechoslovakia bee hives have been wiped out. The power-station burns coal with high levels of arsenic i.e. several hundred ppm, and consequent elevated air levels of As_2O_3 occur. Bees also will pick up and accumulate selenium when pollinating high selenium plants, such as some of the loco-weeds (Astragalus species).

The successful growth of the pollen tube is reported to be pH-dependent and also to be influenced by the presence of toxic heavy metals such as zinc and copper. The fertilization of fern archegonia has been reported to be inhibited by acid solutions and acid rain, L. Evans, (personal communication). L. Schlicter, a graduate student in botany at University of Toronto, has recently shown that the successful post-fertilization steps in embryo development of frog eggs is inhibited by even quite minor decreases in pH below 6.0 and that multiple-fertilization of an egg, which normally are precluded, can occur under these acidic conditions. The consequence is an early aborted embryo. Effects on trout eggs, on New Jersey frogs and on reproductive success in planktonic crustaceans have been reported by a number of workers, e.g. Krishna (1953), Gosner and Black (1957), Havas (1980).

Other Factors which Influence the Outcome of Metal Impacts

It does seem to be the case that the damage to ecosystems from airborne metals, as well as from gaseous pollutants, is greatest when the individuals in the ecosystem are metabolically most active. Thus, the damage to forest ecosystems in temperate zones is clearly greatest in the summer growing season. Damage during the day when stomata are open is greater than at night when they are closed. The lichens and mosses are most susceptible when they are moist and photosynthesizing actively. In dry or arid habitats, such as the deserts of Arizona, the damage from large smelter-emitted SO_2 and copper particulate is minimal in contrast to that of wetter areas such as Palmerton Pennsylvania, Ducktown Tennessee or Sudbury, Ontario. This probably partly relates to metabolic activity including the percentage of time stomata remain open, but also to the activity of the root systems. If o follows through with this generalization, then w can predict that arctic regions with very short growing seasons and very long dormant periods will be less affected by equivalent metal pollutant inputs (or SO_2, O_3 or Fl inputs) than woul Temperate or especially Tropic Rain Forest systems. Equally, one can predict that the mor arid an area, the less susceptible this area's vegetation will be to toxic damage.

The importance of the longevity of the individual also needs to be stressed. Damage t long-lived trees may take a long time to become apparent and finally perhaps only through their inability to reproduce. Equivalent reproductiv failure in an annual will obviously be very rapidly apparent. Metal stresses often seem to favour perennial plants with largely vegetative reproduction, such as grasses and sedges. The equivalent aquatic examples would be that of fish compared with planktonic algae or crustacea

Finally, it must be emphasised that the initial sensitivities of the species, populatio and individuals of an area when first subject t metal stress, are not the final response. Whil pre-adaptation or pre-sensitivity may allow an initial selection and sorting, the stressed environment represents a changing habitat in which evolutionary change occurs. The occurre of metal-tolerant grasses on mine waste sites i well known. The ability of some of these grass to evolve multiple-metal tolerances and co-tolerances is now also receiving attention (Tatsuyama and others 1975, Cox and Hutchinson 1980). Even in habitats such as the Smoking Hills of arctic Canada, where pond water pH's may rea as low as 1.8 and soil pH's to < 3.0 from the initial values of pH > 7.0, some organisms do survive. These even have the ability to tolera the high acidity, low nitrogen and phosphorus availability and the extremely elevated levels normally toxic metals such as aluminium, mangan ferric ion and zinc, Hutchinson and others (19). At the extreme, some organisms seem to have evolved specifically on areas of very elevated metal levels. The occurrence of a legume Beci homblei on copper mineralizations is an exampl of this, in which the plant accumulates enormo levels of copper and also requires concentrati which would be lethal to other plants (Reilly 1967).

While this allows a certain re-assurance a ut the ability of life to thrive under even most adverse conditions, it does not at all influen

he fact that we must be extremely concerned with he accelerating liberation of heavy metals to our gricultural and natural environments. Economic nd social pressures do compel us to take stock. roposals for disposal of metal-contaminated ewage sludge on farm or forest lands have already aused agencies and scientists to think in a much onger time frame than we are used to do.

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Effects of Acidic Precipitation on Health and the Productivity of Forests[1]

Ellis B. Cowling and Leon S. Dochinger[2]

Abstract: Acid precipitation has become a dominant feature of man-induced change in the chemical climate of the earth. But acid precipitation is only one special feature of the changing chemistry of atmospheric deposition in developed and developing regions throughout the world. In recent decades, human activities (mainly increased combustion of fossil fuels and decomposition or combustion of waste products) have greatly increased the total emissions and deposition of beneficial nutrients and injurious substances (such as strong mineral acids) from the atmosphere. Projected increases in the use of fossil fuels, and especially in the use of coal, will add still further to the total burden of beneficial and injurious substances deposited on forest and rangeland ecosystems from the atmosphere. The purpose of this brief paper is to summarize certain important principles concerning the phenomena of acid precipitation and atmospheric deposition and their beneficial and detrimental effects on the health and productivity of forests.

The supply of both beneficial nutrient elements and injurious substances in the atmosphere influence the health and welfare of forests. Plant life as we know it would be impossible without atmospheric sources of carbon dioxide for photosynthesis, nitrogen for biological fixation and proteins synthesis, oxygen for respiration and synthesis of carbohydrates, and water for transpiration and the maintenance of cell turgor.

Some epiphytic plants, such as orchids, spanish moss, and certain lichens, obtain essentially all their nutrients and water from the atmosphere. Although these plants represent an extreme case of dependence on atmospheric resources, many forest trees and some herbaceous plants also derive a significant portion of their nutrients from the atmosphere.

Plants suffer when the concentrations of injurious substances in the atmosphere exceed the amounts they can tolerate. Injurious gases can enter through the stomata of leaf tissues and poison the photosynthetic system of living cells. Toxic particles can accumulate on plant surfaces and injure plant cells. Strong acids can dissolve in rain drops or adsorb to snowflakes and then be deposited in precipitation. Dissolved substances can accumulate in snow where they may be concentrated and released with the first meltwater. In

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all these ways substances transferred from the atmosphere to the biosphere can influence plant growth, beneficially (as in the case of beneficial nutrient elements) or harmfully (as in the case of toxic gases, aerosols, dry particulate matter, and injurious substances dissolved in precipitation).

The growth and productivity of forests are determined by the availability of sixteen elements that are essential for growth and a few that are toxic to plants. The essential elements include nine major elements: carbon, hydrogen, oxygen, nitrogen, phosphorous, potassium, sulfur, calcium, and magnesium and seven minor elements: iron, copper, zinc, manganese, molybdenum, boron, and chlorine.

Some elements are both essential and injurious to plants. For example, sulfur and nitrogen are needed for synthesis of protein, nucleic acids, and other substances; but gaseous sulfur and nitrogen oxides and sulfuric and nitric acid aerosols are also injurious to plants at very low concentrations. Similarly, excess amounts of the minor nutrient elements also can injure plants. Atmospheric fluoride is toxic to plants at 25-50 ppm. Aluminum is the most abundant potentially toxic element in soils. Its availability (and thus its toxicity) is influenced greatly by the acidity of soils, which in turn is influenced by the abundance of acid precipitation.

Uptake of nutrients from atmospheric sources is especially important in natural ecosystems such as lakes, estuaries, wetlands, forests, and rangelands where nutrients from other sources are scarce and where fertilization is not a normal management procedure. But this capacity also increases the vulnerability of terrestrial and aquatic organisms to injury by acid precipitation and toxic aerosols and gases (Galloway and others 1978).

ACID PRECIPITATION AS PART OF A GENERAL PHENOMENON OF ATMOSPHERIC DEPOSITION

Air-borne substances that influence terrestrial plants include sea spray from oceans and large lakes; dust resulting from wind erosion of soil as well as from volcanic and cosmic sources; gases such as CO_2, NH_3, SO_2, H_2S, CH_4, released from decomposing organic matter and volcanoes; biogenic particles such as spores, hyphal fragments, bacteria, and pollen; particulate matter, aerosols, and gases produced by wild fires and controlled burning of agricultural, forest and urban wastes as well as from industrial, agricultural residential and commercial heating, and transportation operations (Tamm 1958).

Rain and snow change in chemical composition within, as well as between, precipitation events. In cold climates, acid substances accumulate in the snowpack where they are released in concentrated form with the first melt water and thus cause very sudden increases in acidity of surfac soils, vegetation, and surface waters. Thus a given plant may be subject to beneficial atmospheric influences at one time and to negative influences at another time within a given day, month, growing season, or the years of its development in the case of perennial plants and animals. Even a given substance, such as sulfur or nitrogen dioxides, may be absorbed an utilized as a beneficial nutrient at one concentration in the atmosphere. At another, higher concentration, even on the same day, however, the same substance may be absorbed and found to be toxic or even injurious to the very same pla

Forests and rangelands cover a larger fracti of the total land area of the United States tha all other uses of land combined. For this reas terrestrial vegetation, soils, and surface wate are the primary deposition sites for precipitat and airborne particulate matter of all types. Trees develop very large canopies of leaves and branches that extend high into the air. Thus, forests and range plants provide an extremely large surface for deposition and assimilation o both beneficial nutrient elements and injurious substances dispersed in the atmosphere.

Direct injury to vegetation is most likely when a particularly vulnerable life form is exposed at a particularly vulnerable life stage and is growing in a poorly buffered environment during a season of the year when acid precipitation is most likely. For example, a tender you plant, at the earliest stage of reproduction, growing on a poorly buffered sandy soil, during a heavy spring rain is especially vulnerable to acid rain.

Both herbaceous and perennial plants are subject to changes in atmospheric deposition within a given growing season. In addition, perennial shrubs and trees live in the same environment for many years or even decades. As a result, they are subject to very long-term changes in the chemistry of the air and precipitation.

The effect of acid precipitation on plants i only one facet of the much larger subject of atmospheric/plant/soil interactions. Acidity in precipitation should be understood as a reflection not only of the amounts of substance yielding hydrogen ions (such as sulfuric, nitri hydrochloric, and organic acids) but also of the total balance between all the cations and anions dissolved in precipitation. These majo anions and cations include H^+, NH_4^+, NO_3^-, $SO_4^=$ and many others including K^+, Na^+, Ca^{++}, Mg^{++}, CO_3^-, Cl^-, and $PO_4^{\equiv}$.

For all of the above reasons, it is difficu to assess the effects of acids in rain or snow in isolation from the general chemistry of precipitation and atmospheric deposition. Als the effects of a given "acid rain" or a prevai condition of "acid rains" are very complex,

variable in time, and involve significant interactions that are only partially understood.

POSSIBLE DETRIMENTAL EFFECTS OF ACID PRECIPITATION ON VEGETATION

A partial list of theoretical effects of acid precipitation on vegetation was developed earlier by Tamm and Cowling (1977) and is reproduced in Table 1. The effects are classified as either direct or indirect, although most direct effects will have many indirect consequences as well. A decreased rate of growth is the expected consequence of most of the effects postulated in Table 1 but unequivocal evidence of significant growth effects have yet to be demonstrated in forest or range ecosystems. Specific biological effects that have been proven to occur in at least one experimental plant are marked with an asterisk (*) in Table 1.

Many factors (i.e., genetic composition, biotic and abiotic stress factors, dose of pollutant, and pollutant combinations) affect the impact of acid precipitation and other pollutants on terrestrial plants and animals. Variation in any one factor can result in variation in the nature and magnitude of pollutant effects. This is shown simplistically in Figure 1.

Previously, it was believed that the essential and potentially toxic elements listed above were taken up by plants almost entirely from the soil solution. Now, it is recognized that airborne gases, particulate matter, and aerosols significantly augment the supply of both essential and injurious elements. All of the substances

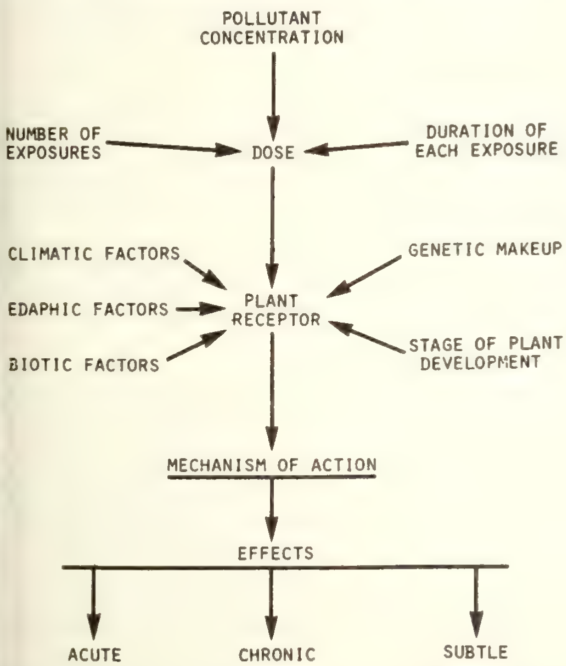

Figure 1. Conceptual model of factors involved in air pollution effects on vegetation (Heck and others 1977).

listed above can be taken up readily through foliar organs as well as by absorption from the soil solution (Tamm 1958; Wittwer and Bukovac 1969).

Much larger amounts of essential nutrients are required for sustained-yield agriculture than for sustained-yield range management or hardwood or softwood forestry. This is true in rangelands because biomass yields are very low and in forests because the parts of trees that usually are harvested (the wood and bark of tree stems) contain much less of most essential elements than the seeds and fruits that are commonly harvested in agriculture. This is a major reason why fertilization is so common in agriculture and so rare in forestry and range management. In some forested regions, atmospheric deposition alone is more than adequate to permit harvesting of crop after crop of trees without fertilizing the forest. This is much less likely to remain so, as more and more of the nutrient-rich branches, foliage, and roots of trees are harvested in so-called "whole-tree chipping" and other modern harvesting practices.

Some scientists believe that acid rain and snow are deposited directly onto soils where acid substances can be neutralized in well-buffered soils or by applications of lime. This is true on some agricultural lands, especially after harvest, but is not true in forests, rangelands, or even on most agricultural lands during the growing season. Most raindrops are intercepted by the foliage of plants where substances dissolved in rain can induce various physiological changes before reaching the soil (see Table 1). In a mature forest, for example, rain will wash over at least three tiers of foliage before reaching the soil.

SOURCES, AMOUNTS, AND DISTANCES OF TRANSPORT OF BENEFICIAL AND INJURIOUS SUBSTANCES IN THE ATMOSPHERE

Forest, range, and aquatic biologists are becoming increasingly concerned about atmospheric transport and deposition of both nutritionally beneficial and potentially injurious substances for three major reasons:

(1) vegetation, soils, and surface waters are the primary deposition sites for precipitation and airborne particulate matter;

(2) atmospheric deposition constitutes an important source of nutrients and potentially injurious substances that affect the productivity and stability of agricultural, forest, and aquatic ecosystems; and

(3) human activities are steadily increasing the amounts and variety of substances dispersed in the atmosphere (Oden 1968; Bolin and others 1972).

Table 1--Potential Effects of Acid Precipitation on Terrestrial Vegetation

DIRECT EFFECTS

*1. Damage to protective surface structures such as cuticle. Damage to surface structures may occur due to accelerated erosion of the cuticular layer that protects most foliar organs. It also could result from direct injury to surface cells by high concentrations of sulfuric acid and other harmful substances that are concentrated by evaporation or adherence of soot particles on plant surfaces.

*2. Interference with normal functions of guard cells. Malfunction of guard cells will lead to loss of control of stomata and thus altered rates of transpiration and gas-exchange processes and possibly increased susceptibility to penetration by leaf-attacking plant pathogens.

*3. Poisoning of plant cells after diffusion of acidic substances through stomata or cuticle. This could lead to development of necrotic or senescent spots on foliar organs including leaves, flowers, twigs, and branches.

*4. Disturbance of normal metabolism or growth processes without necrosis of plant cells. Such disturbance may lead to decreased photosynthetic efficiency, altered respiratory patterns and intermediary metabolism, as well as abnormal development or premature senescence of leaves or other organs.

*5. Alteration of leaf- and root-exudation processes. Such alterations may lead to changes in populations of leaf-surface and root-surface microorganisms, including nitrogen-fixing organisms.

*6. Interference with reproduction processes. Such interference may be achieved by decreasing the viability of pollen, interference with fertilization, decreased fruit or seed production, decreased germinability of seeds, etc.

7. Synergistic interaction with other environmental stress factors. Such reinforcing interactions may occur with gaseous sulfur dioxide, ozone, fluoride, soot particles, and other air pollutants as well as drought, flooding, etc.

INDIRECT EFFECTS

*1. Accelerated leaching of substances from foliar organs. Damage to cuticle and surface cells may lead to accelerated leaching of mineral elements and organic substances from leaves, twigs, branches, and stems.

2. Increased susceptibility to drought and other environmental stress factors. Erosion of cuticle, interference with normal functioning of guard cells, and direct injury to surface cells may lead to increased evapotranspiration from foliar organs and vulnerability to drought, air pollutants, and other environmental stress factors.

*3. Alteration of symbiotic associations. Changes in leaf- and root-exudation processes and accelerated leaching of organic and inorganic substances from plants may affect the formation, development, balance, and function of symbiotic associations, such as mycorrhizae, nitrogen-fixing organisms, lichens, etc.

*4. Alteration of host-parasite interactions. Resistance and/or susceptibility to biotic pathogens, parasites, and insects may be altered by subjecting plants to any environmental stress. Acid precipitation may increase the susceptibility of plants to these injurious agents, alter their capacity to tolerate disease or injury, or alter the virulence of pathogens. The effects of acidic precipitation may vary with the following: the nature of the pathogen involved (whether a fungus, bacterium, mycoplasma, virus, nematode, parasitic seed plant, insect, or multiple-pathogen complex); the species, age and physiological status of the host; and the stage in the disease cycle in which the acidic stress is appled, for example, acidic rain might decrease the infective capacity of bacteria before infection and increase the susceptibility of the host to disease development after infection.

Source: Tamm and Cowling, 1977

Recent increases in the deposition of sub-
ances on terrestrial vegetation are due mainly increases in combustion of fossil fuels in lustrial enterprises, residential heating, ansportation, and agricultural operations. viously, it was believed that most of these erials fell out of the atmosphere near the e of emission. Now it is recognized, particu- ly with increased use of tall stacks at power nts, that atmospheric processes can lead to ensive mixing and both chemical and physical eractions and transformations of atmospheric ticles, aerosols, and gases. Furthermore, se substances and their reaction products are persed by meteorological processes and finally deposited on vegetation or soils as much as eral hundreds of kilometers from the original rces of emission. The recent fallout of ioactive materials in the eastern United States the result of atomic explosions in the Peoples ublic of China provides a dramatic reminder of long-distance transport and deposition of lutants.

The amounts of substances introduced delib- tely or inadvertently by man are becoming so ge that man is becoming a major force in the geochemistry of the earth (Kovda 1975). This shown in table 2 which contains a tabulation data on annual output of fertilizers, indus- al dusts, garbage and other urban wastes and products, mine refuse, and discharges of osols and gases mainly from the combustion fossil fuels. All these categories of matter becoming comparable in magnitude to the charges of dissolved and suspended substances all the rivers of the world, the annual yield photosynthetic products, or the cycling of rganic elements in the earth as a whole. -made emissions into the atmosphere are also very large, as shown in table 3. Most gases, carbon oxides, and aerosols result from the combustion of fossil fuels. A very large part of these global emissions are produced in the United States.

ale 2--Biogeochemical and Technological Forces he Biosphere of the Earth

phere Components	Tons/Year
eochemical processes:	1×10^{10}
obal yield of photosynthesis	1×10^{10}
cle of inorganic elements	1×10^{10}
r discharges:	
ssolved substances	3×10^{9}
spended substances	2×10^{10}
ropogenic sources:	
tput of fertilizers	3×10^{8}
dustrial dust	3×10^{8}
rbage, urban wastes and byproducts	2×10^{10}
ne refuse	5×10^{9}
rosols and gas discharges	1×10^{9}

ce: Kovda, 1975

If the United States continues to add to the amount of substances dispersed in the atmosphere and deposited into the biosphere of the earth, it is essential that we measure the amount and chemical form of the deposited matter and understand the biological consequences of that deposition. Regrettably our understanding of these processes in the United States is very fragmentary. Fortunately, however, more extensive measurements of atmospheric deposition and its biological consequences have been made in Europe, where an atmospheric-deposition network has been maintained since the late 1940s (Oden 1968).

The European Air Chemistry Network began in Sweden and has gradually spread to include most of western Europe and parts of eastern Europe, including Poland and the Soviet Union. Since the mid 1950's, a network of about 100 stations has made monthly measurements of changes in the chemistry of precipitation. The substances analyzed at most of these stations include the following major cations and anions: NH_4, Na, Ca, K, Mg, SO_4, NO_3, PO_4, Cl as well as pH, conductivity, and titratable acidity and akla- linity. These data have shown various long-term trends. For example, the amount of nitrate nitrogen in precipitation (an important fertilizer element) increased markedly in many parts of Europe during the fifteen years between 1955 and 1970. Nitrate nitrogen helps plants grow. Thus, the nitrogen added in precipitation probably increased yields of agricultural and forest crops.

But not all the substances detected in precipitation were beneficial. Long-term trends of injurious sulfate and hydrogen ions also were detected from 1955-1970. The latter changes were attributed to strong acids formed in the atmosphere, mainly from oxides of sulfur and nitrogen produced during combustion of fossil fuels. More recent data show that these trends of increasing acidity are

Table 3--Anthropogenic Emissions into the Atmosphere

Types of Emissions	Tons/Year
Dust	2.5×10^{8}
Gases (mainly SO_2, HC and NO_x)	6.5×10^{8}
Carbon oxides ($CO + CO_2$)	2.0×10^{9}
Aerosols	1.0×10^{9}
Note: Doubling about every 7-10 years	

Source: Kovda, 1975

continuing although the relative contribution of sulfuric and nitric acids is changing (Likens 1976).

CHANGES IN THE CHEMISTRY OF PRECIPITATION IN THE UNITED STATES

Some monitoring of the chemistry of precipitation has been carried on in the United States (Feth and others 1964; Lodge and others 1968). Many of these studies provide excellent and reliable information about the acidity of precipitation. But most studies in this country have suffered from three major shortcomings:

1. The data were collected for a limited land area--typically only a single point or a few points in one or two states (Gambell and Fisher 1966);

2. The data were collected for very limited periods of time--typically only one or two years;

3. Very few direct measurements of acidity have been made.

There is only one location in the United States--at Hubbard Brook Experiment Forest in New Hampshire--where the acidity of rain has been measured directly and consistently for as long as 10 years. The longest-term national monitoring program was operated by the U.S. Public Health Service for 6 years, from 1960 to 1966 (Lodge and others 1968). These data showed that precipitation generally is acidic east and generally alkaline west of the Mississippi River, the latter because of alkaline dust in the air.

Using fragmentary bits of information, obtained indirectly and in limited areas and periods of time, Cogbill and Likens (1974) managed to calculate the probable changes in average acidity of rainfall in various parts of the eastern United States from 1955-1973. Precipitation in a large portion of the eastern United States was less than pH 5.6 in 1955-56; the zone of greatest acidity (lowest pH) was generally consistent with the zone where sulfur emissions were high--parts of Ohio, Pennsylvania, West Virginia, New York, and New England. By 1973, however, the area with an average pH of rain below 4.5 had extended to include parts of Missouri, Arkansas, Mississippi, Alabama, Georgia, South Carolina, Virginia, Kentucky, Illinois, Michigan, and further north into New England and Canada. Essentially, it embraces most of the area east of the Mississippi River. Individual rainstorms with pH values between 2.1 and 3.6 have been reported in New York, Illinois, Indiana, New Hampshire, Massachusetts and North Carolina--in some cases many hundreds of kilometers from major sources of air pollution (Likens 1976).

The relative contribution of sulfate and nitrate to the total acidity of precipitation apparently changed markedly during the years sinc 1964-65. At Hubbard Brook, New Hampshire, the ratio of sulfate to nitrate changed from 83:15 in 1964 to 66:30 in 1974. During this same decade, the total input of hydrogen ions increase by 36 pct. Thus, most of this increase appears to be due to increased deposition of nitric acid.

EFFECTS OF ACID PRECIPITATION ON TERRESTRIAL ECOSYSTEMS

Cowling (1980a, 1980b) has recently completed 2 historical analyses of progress in scientific and public understanding of acid precipitation and its biological consequences. Several publications are worthy of special notice in this connection. The pioneering researches by Robert Smith, Eville Gorham and Svante Odén dealt with effects on lake waters, aquatic vegetation, terrestrial vegetation, and human health (Smith 1872; Gorham 1958, 1976; Odén 1968). In 1971, Bolin and his co-workers completed the Swedish Case Study Contribution to the United Nations' Conference on the Human Environment (Bolin and others 1972). In 1972, three Norwegian research organizations established a special research project called Acid Precipitation: Effects on Forests and Fish, with an annual budget of 10,000,000 Norwegian kroner (U. S. $2,000,000). The first International Conference on Acid Precipitation and the Forest Ecosystem was held at Ohio State University at Columbus in May of 1975 (Dochinger and Seliga 1976a). In June of 1976, an International Conference on Effects of Acid Precipitation was held at Telemark, Norway, and the major papers assembled for this meeting published by Braekke (1976) and in a special issue of Ambio (1976). In November, 1976, Gene Likens published his summary report in Chemical and Engineering News (Likens 1976). In May, 197 a NATO Advanced Research Institute on Ecologica Effects of Acid Precipitation was held at Toronto, Canada (Hutchinson and Havas 1980). In September, 1978, the Central Electricity Generating Board in England and the Electric Power Researc Institute in the United States sponsored an international symposium on the biological effec of acid precipitation (Howells 1979). In March 1980, the Norwegian special project on acid precipitation sponsored an International Confer on Effects of Acid Precipitation in Sandefjord, Norway (SNSF 1980).

The effects of acid precipitation on terrestrial ecosystems generally have been less well documented than those on populations of freshwater fish an other aquatic organisms (Ambio 1976; Braekke 19). Nevertheless, certain definite effects have bee reported. The most striking of these effects w the development of peat moss (Sphagnum sp.) as submarine, rather than a terrestrial plant in acidified lakes and streams in Sweden. Dense mats of Sphagnum and heavy felts of algae devel on the bottom of these lakes in water as deep a 18 m. This growth is reported by Grahn and others (1974) to induce oligotrophication (opposite of eutrophication)--a self-accelerati

rocess that leads to a substantial nutrient npoverishment of lake waters.

Analyses of forest growth in southern Sweden rom 1896 to 1965 showed a 2 to 7 percent decrease 1 growth between 1950 and 1965. Johnsson and ındberg (1972) "found no good reason for attrib- :ing [this] reduction in growth to any cause other ıan acidification." Similar attempts to quantify ›ssible effects on growth of forests in the ıited States have been inconclusive.

Both direct and indirect damage to crops and :rests have been reported by various investiga- rs in laboratory, greenhouse, and field experi- nts in which synthetic rain equivalent in chemical mposition and rate of deposition to natural rains s been applied. The biological effects recorded these experiments include the following owling 1980c):

- --Induction of necrotic lesions on foliage;
- --Loss of nutrients due to leaching from leaves and other foliar organs;
- --Predisposition of plants to infection by bacterial and fungal pathogens;
- --Accelerated erosion of waxes on leaf surfaces;
- --Inhibition of nodulation of legumes leading to decreased fixation of nitrogen by symbiotic bacteria; and
- --Reduced rates of decomposition of leaf litter leading to decreased mineralization of organically-bound nutrients.

Abrahamsen (1980) has recently summarized many ırs of research showing both positive and ;ative effects of acid precipitation on forest ›wth. He concludes with the following general itements: "Apart from possible direct effects acid precipitation on forest trees, the effects forest growth can be considered a nutrition blem . . . increased deposition of N and S can regarded as a . . . fertilization effect, and increased leaching of nutrient cations . . . an oligotrophication or acidification effect . the general hypothesis that acid precipita- n significantly will decrease forest production r large areas must be revalued. The deposition N and to some extent S . . . is likely to rease forest production. Reduced growth may expected where or when nutrients like Mg and sibly K are the growth limiting elements."

RECENT INITIATIVES DEALING WITH ACID PRECIPITATION AND ITS BIOLOGICAL EFFECTS

In 1975, the National Academy of Sciences' mittee on Atmospheric Sciences published its ort on Atmospheric Chemistry: Problems and e (NAS 1975). Growing awareness of important luences of acid precipitation on fish popula- is and potential effects on forest and crop its led the U. S. Forest Service to sponsor First International Symposium on Acid Precipi- on and the Forest Ecosystem at Columbus, in May, 1975. The proceedings of this posium and the Associated Workshop Report were published by Dochinger and Seliga (1976a, 1976b). At Congressional hearings in July, 1975, Cowling (1976) testified on the inadequacy of research in the United States on Acid Precipitation and its biological consequences. Specifically, the lack of a coordinated program of research on ecological effects and lack of a stable monitoring network were recognized as primary causes of our profound ignorance of acid precipitation. In the spring of 1976, however, a cadre of scientists in various institutions and agencies throughout the United States began the process of creating the National Atmospheric Deposition Program (NADP) to meet these two critical needs (Kennedy 1977; Galloway and Cowling 1978).

In the fall of 1977, the President's Council on Environmental Quality contracted with the NADP for the drafting of "A National Program for Assessing the Problem of Atmospheric Deposition (Acid Rain)." This publication (Galloway and others 1978) provided the basis for a Presidential Initiative on acid precipitation which President Carter announced on August 2, 1979 in his Second Environmental Message (Carter 1979). This initiative calls for a 10-year long, $10,000,000 per year program of research on the causes and consequences of acid precipitation. A standing Acid Rain Coordinating Committee was established by the President to plan and manage the program. Leadership for the Committee is provided by co-chairmen from the Department of Agriculture and the Environmental Protection Agency. At the present time, the Acid Rain Coordinating Committee is drafting a coherent program of research on atmospheric chemistry and transport, chemical and biological monitoring, ecological and materials-damage effects, economic assessments, and public-policy options for control of acid precipitation and/or amelioration of its ecological effects.

Wetstone (1980) has recently summarized the biological and materials-damage effects of acid precipitation in relation to the pollution-control laws in North America.

In conclusion, the Presidential Initiative on Acid Precipitation, coupled with growing Congressional, public, and private-industrial interest in acid precipitation research, provide a basis for increasing hope that the United States will do its part, together with Sweden, Norway, England, Canada and other nations, to meet the challenge of continuing economic development with adequate safeguards for the quality of life and the long-term productivity of ecosystems on which our good life critically depends.

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Simulation Modeling of the Effects of Chronic Pollutant Stress on Plant Processes and Plant Community Dynamics

Modeling Pollutant Uptake and Effects on the Soil-Plant-Litter System[1]

R. J. Luxmoore[2]

Abstract: Five coupled models of water, carbon, and chemical dynamics in a soil-plant-litter system are outlined. Algorithms defining gaseous and particulate pollutant uptake are described along with functions for chemical effects on plant growth and litter decomposition. Some simulation results of a deciduous forest illustrate the importance of diurnal and annual cycles of environmental conditions on pollutant movement in vegetation. This modeling approach has provided (1) insights into plant physiological processes and their interactions, (2) identification of plant properties important in pollutant uptake, (3) alternative hypotheses about pollutant effects, and (4) a unified basis for assessment of diurnal and long-term pollutant impacts on plant communities.

"and all the king's horses and all the king's men couldn't put Humpty together again."

from Humpty Dumpty, Anon.

The discouraging words of the nursery rhyme suggest that the synthesis of bits of an egg to a whole will not happen at least while horses and men are in charge! Our task of trying to couple together bits and pieces of mechanistic information about the physiology of trees and responses to soil and atmospheric environments is no less awesome a challenge. Simulation modeling is a remarkable tool for meeting this challenge, since through mathematics coupled relationships may be quantified. In this paper, an outline is presented of five mode that link together and provide a framework f study of pollutant uptake and effects in t whole plant environment complex. Some applic tions are shown and the use of models analysis of experiments is explored. Lastl some speculations are presented about polluta impacts on whole plants and their diurn metabolism.

MODELING THE SOIL-PLANT-LITTER SYSTEM

The development of a unified approach to t modeling of terrestrial processes has be undertaken at Oak Ridge. Five component mode of water, carbon, and chemical dynamics in soil-plant-litter system were constructed a linked together (Baes et al. 1976). The mode (table 1) are deterministic. The flow process are dependent on gradient terms calculated the models to provide the flow driving forc and empirical inputs are used to represent pat way resistances or conductivities. Fl directions are not predetermined and the mode can be applied to a range of different soi plant systems (e.g., coniferous, deciduo forest) by changing the empirical properties the input data. The reader is referred to t documentation reports (table 1) for furth details.

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[1]Presented at the Symposium on Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, June 22-27, 1980, Riverside, California, U.S.A.

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able 1--Some attributes of coupled models escribing carbon, water, and chemical dynamics the soil-plant-litter system.

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MPONENT	WATER	SOIL EXCHANGE	CARBON	ROOT SOLUTE UPTAKE	SOLUTES
ME	PROSPER (TEHM)	SCEHM	CERES	DIFMAS	DRYADS
E STEP	15 OR 60 min.	15 OR 60 min	60 min	15 OR 60 min	15 OR 60 min
RIBUTES	EVAPOTRANSPIRATION BY COMBINATION EQUATION SOIL WATER FLOW BY DARCY FLOW EQUATION. USES EMPIRICAL RELATIONSHIP BETWEEN SURFACE RESISTANCE AND SURFACE WATER POTENTIAL EMPIRICAL DATA FOR SOIL HYDRAU LIC PROPERTIES	USES EMPIRICAL DISTRIBUTION COEFFICIENT (Kd) FOR SOIL OF INTEREST	CO_2 DIFFUSION EQUATION FOR NET PHOTOSYN THESIS SUBSTRATE GRADI ENT EQUATION FOR TRANSLOCATION USES INPUT VALUES FOR POTENTIAL GROWTH OF LEAF, STEM, ROOT, FRUIT EMPIRICAL LITTER DECOMPOSITION RELATIONSHIPS	IMPLEMENTS MODEL OF DIFFUSION AND MASS FLOW OF SOLUTES TO ROOTS BY BALDWIN, NYE AND TINKER (1973)	SOLUTE UPTAKE BY ROOTS AND LEAVES DIFFUSIVE GAS UPTAKE BY LEAVES GRADIENT EQUATION FOR PHLOEM TRANS LOCATION TRANSPIRATION FLUX USED FOR XYLEM TRANSPORT PLANT DEMAND FUNC TION DETERMINED BY POTENTIAL SOLUTE CONCENTRATION INPUT VALUES
ERENCE	HUFF et al (1977)	BEGOVICH AND JACKSON (1975)	DIXON et al (1978)	LUXMOORE et al (1978)	LUXMOORE et al (1978)

The coupling between models (fig. 1) shows tat every model has information transfer with least two other models, and these take place either an hourly time step or every 15 min-ues during storm events. Hourly values of sto-matal resistance and plant water potential from PSPER are used in CERES to determine photo-sthesis and growth respectively. Leaf and rt growth in turn influence transpiration and ts soil water flow. During rainfall, infil-tation and the movement of water between soil lyers (calculated in PROSPER) is used in the sil chemistry model (SCEHM) to calculate chemi-cl fluxes. Chemical concentration and root wter uptake information are used in DIFMAS to clculate chemical uptake into root by diffusion a mass flow. Chemicals within the plant are mved up in the transpiration stream and down in t phloem pathway.

This set of models can be run for simulation piods of several years and annual budgets for wer, carbon and chemicals can be evaluated as wl as detailed results for hourly periods of ierest. The algorithms defining gaseous and pticulate pollutant uptake and effects on pnt growth and litter decomposition are out-led in the next two sections along with emple simulation results.

AIR POLLUTANT UPTAKE

The uptake of air pollutants by vegetation m occur directly through leaves (gaseous and pticulate) or indirectly through roots after t pollutants have been incorporated into soil. Gaseous uptake is represented by a diffusion eqation (same form as the photosynthesis eqation). Thus

$$U_g = \frac{(g_e - g_i)* g_d}{r_a + r_s + r_m} ,$$

whre g_e is the external pollutant concentration (ml/ml)

g_i is the internal pollutant concentration (ml/ml)

g_e is gas density (μg/ml)

r_a is boundary layer diffusion resistance (sec/cm)

r_s is stomatal resistance (sec/cm)

r_m is mesophyll resistance (sec/cm)

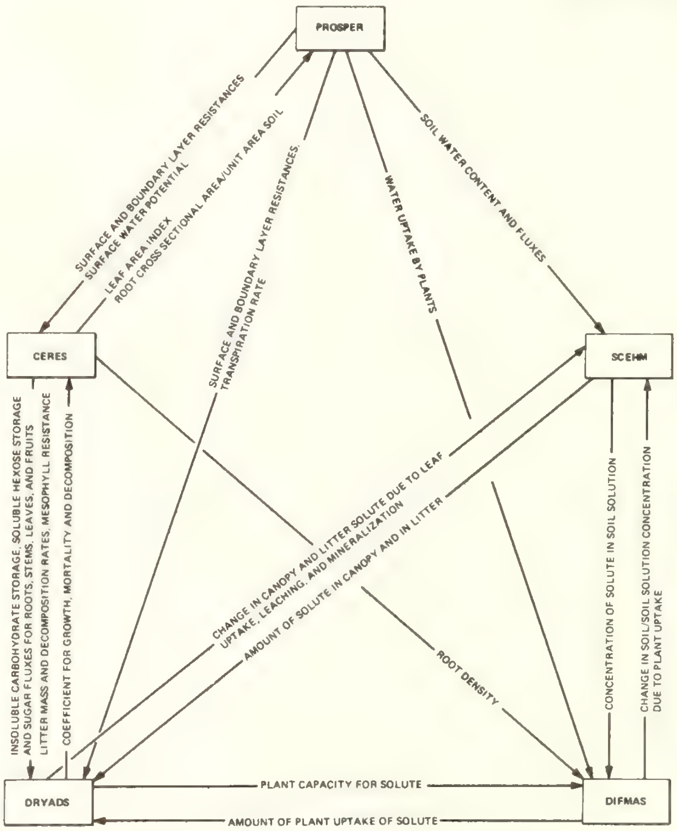
U_g is uptake ($\mu g/cm^2$ leaf/sec)

The value of g_i is made to vary between zero and g_e depending on the level of pollutant in leaf storage (E_i) as follows,

$$g_i = g_e * (1 - \frac{E_m - E_i}{E_m}) .$$

E_m is the maximum allowable level of pollutant in leaf storage, an input parameter. Operationally this is the pollutant level at which the leaf tissue becomes necrotic.

ORNL-DWG 75-15812R2



PROSPER	soil-plant-atmosphere water flow model
CERES	carbon dynamics of vegetation and litter
SCEHM	soil chemistry model
DIFMAS	diffusion and mass flow of chemicals to roots
DRYADS	chemical dynamics of vegetation and litter

Figure 1--Coupling of five process models that describe hourly carbon, water, and solute dynamics of the soil-plant-litter system.

Sulfur dioxide uptake by an oak-hickory forest in the vicinity of a lead mining and smelter complex in southeastern Missouri was simulated and results illustrate the behavior of the model. Cumulative sulfur levels in leaves (fig. 2) show a rapid increase on the 25th of August, a day in which the atmospheric SO_2 level was increased 10 fold above ambient. The translocation of sulfur from leaf to stem (fig. 2) clearly shows a diurnal pattern and at elevated rates on the 25th of August. Some of the sulfur material that was transported to the roots, leaked into the transpiration stream and returned from the roots to the stem, albeit in trace amounts. The phloem and xylem transport pathways can allow considerable mobility of solutes between plant tissues according to the simulation. The cumulative sulfur levels in the leaf, stem and root components (fig. 3) show that the majority of sulfur remained in the leaves. The value of 8×10^5 μg S/m^2 is equivalent to a leaf concentration of 180 ppm.

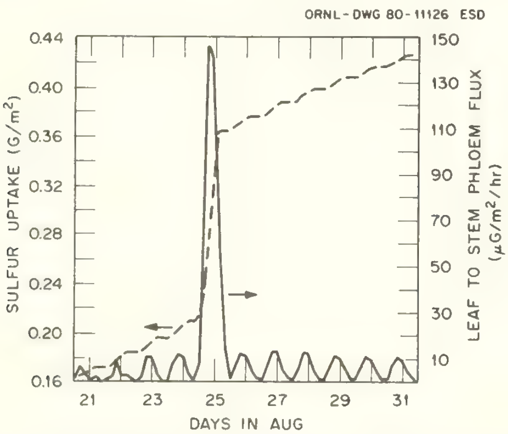


Figure 2--Simulated cumulative sulfur dioxide uptake by vegetation (g/m^2) and leaf to stem phloem translocation rate (μg/m^2/h) for 11 days in August.

The uptake of pollutants from particulates deposited on leaves (U_l) is represented by a gradient equation using empirical input values for the cuticular conductivity (k_l) and thickness (W). Thus,

$$U_l = k_l \frac{(S_e - S_i)}{W} ,$$

where S_e is the external pollutant on leaf surface (g/m^2 land)

S_i is the internal pollutant within foliage (g/m^2 land)

The amount of dissolved pollutant on leaf surfaces is calculated as the lesser of either the product of solubility and the water volume on leaves (interception) or the current amount of pollutant on leaves. The soluble pollutant within leaves (S_i) is assumed to be uniformly distributed and has one of two fates. It may b transported to other plant parts or be incorporated in the leaf in an immobile form. The cuticular uptake process is considered reversibl in the model. Thus during rainfall, wash-of occurs and if S_e becomes less than S_i, the leaching of pollutant out of leaves will occur.

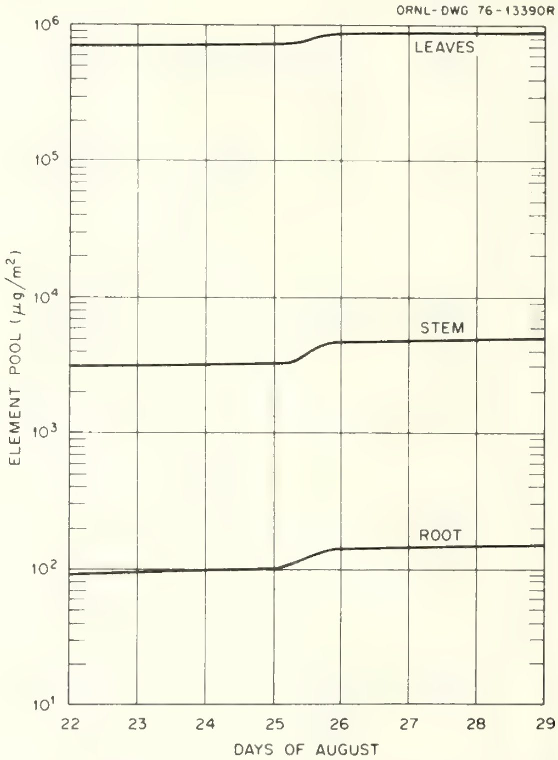


Figure 3--Simulated sulfur elemental accumulation in leaf, stem, and root tissue (μg/m^2 resulting from gaseous uptake.

Sensitivity analysis of the leaf cuticle conductivity (figs. 4a,b) shows that greate conductivity is associated with greater chemica (zinc in the example) uptake by leaves and slightly reduced uptake of zinc from the soi solution (Begovich and Luxmoore 1979). Thi latter and more subtle effect is induced by th higher zinc level in the plant with higher con ductivity which feeds back a reduced chemica demand in the root uptake algorithm. It is pos sible that subtle effects may become significan when integrated over long time periods. Cuticu lar conductivity and the equivalent property a the root-soil interface (root conductivity, k_r were shown to be very sensitive parameters the model, and yet these are perhaps the leas well characterized experimentally. Results fro a sensitivity analysis of root conductivity lead uptake (table 2) show large increases uptake by roots and lead concentration in tre tissues with increase in k_r from 10^{-10} cm/se to 10^{-6} cm/sec. The simulations also sh that pollutants accumulate preferentially in t leaf and root, the sites of pollutant entry. modification has subsequently been added to t model to allow chelation of chemical within t

plant (Luxmoore and Begovich 1979) which has the effect of increasing the mobility of pollutant within the plant. Thus, the site of pollutant entry may not be the site of accumulation.

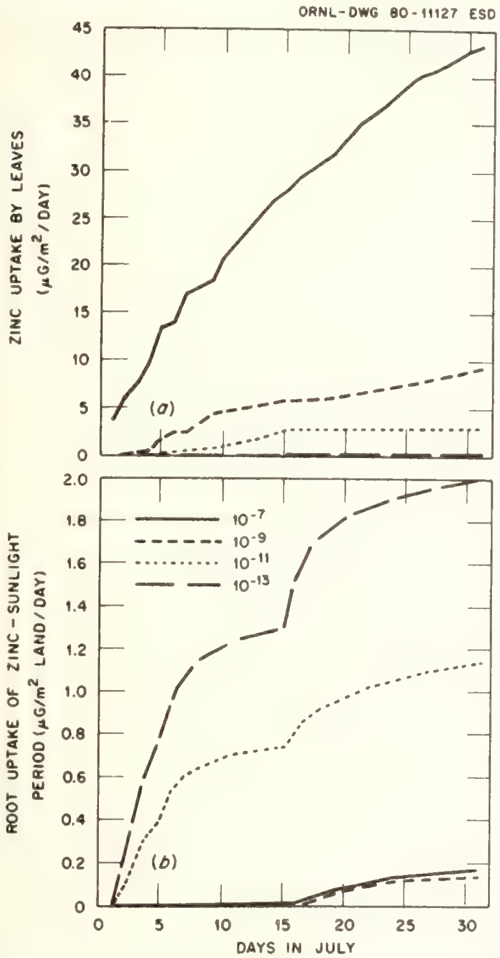


Figure 4--a. Influence of leaf cuticle permeability on zinc uptake by leaves.
b. Influence of leaf cuticle permeability on zinc uptake by roots.

The monthly pattern of lead uptake by roots and foliage simulated for an oak forest near a mine-smelter complex during the first year of operation shows that uptake corresponds with the growing season (table 3). The major proportion (88%) of root uptake occurred during the day chiefly due to two complementary transportation processes; the mass flow of pollutant to roots and mass flow of pollutant from roots to shoots. The latter was the controlling process in the simulations. Overall, leaf uptake was more than double that simulated for roots for the first year of smelter operation.

Table 3--Simulated root and leaf uptake, (mg Pb/m^2 land/month) of lead by oak vegetation in the vicinity of a mine-smelter complex.

Month	Root		Leaf
	Day	Night	
Jan.	0	0	0
Feb.	0	0	0
March	57	4	250
April	213	13	410
May	243	28	890
June	196	45	1190
July	286	41	1130
Aug.	285	37	890
Sept.	315	40	420
Oct.	226	38	20
Nov.	0	0	0
Dec.	0	0	0
Total	1821	246	5200

Table 2--Sensitivity of annual root lead uptake and tissue concentration (prior to leaf fall) in an oak forest to change in the root solute conductivity parameter (k_r).

k_r (cm/s)	Annual root uptake (μg/cm^2/year)	September tissue concentration (ppm)					
		Leaf	Stem		Root		Fruit
			Sapwood	Heartwood	Sapwood	Heartwood	
10^{-4}	156.1	309	854.0	3.30	967	10.2	264.0
10^{-5}	143.3	258	774.0	2.80	961	9.9	191.0
10^{-6}	128.0	242	683.0	2.32	993	11.7	251.0
10^{-8}	20.7	113	5.06	0.01	432	3.1	1.2
10^{-10}	0.52	112	0.48	0.003	11	0.1	0.1

Pollutant Impacts

Simple ramp functions are used to determine pollutant effects on the growth and decomposition of leaf, stem, root and fruit components. Separate ramp functions for either growth effects (fig. 5) or control of decomposition in the litter (same form as for growth effects) represent ranges of chemical deficiency, sufficiency, and toxicity as the chemical concentration increases. Hypotheses concerning beneficial (fertilizer) and toxic pollutant effects can thus be examined. The product of the growth coefficient and tissue growth rate (from CERES) provides a modified growth rate due to pollutant effects.

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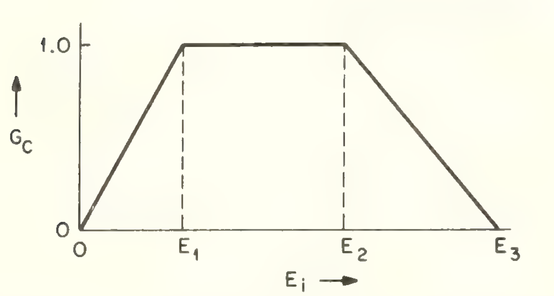

Figure 5--The relationship between the growth coefficient (G_c) and the amount of element in tissue (E_i) used to represent deficiency ($E_i < E_1$)m sufficiency ($E_1 < E_i < E_2$), and toxicity ($E_i > E_2$) effects of the elements on tissue growth rate.

A six-year simulation of heavy metal deposition, transport, and uptake in an oak-hickory forest in southeastern Missouri showed that the lead accumulation was greatest in the litter (Luxmoore et al. 1978). Root uptake of lead increased through the six-year period, whereas leaf uptake was a constant for the repetitive annual deposition of 25 g Pb/m . Due to the buildup of lead in the plant tissues, the mortality of plant parts returned increasingly greater amounts of lead to the litter system . The litter dry weight increased through the six-year period by 949 g/m^2. This compares reasonably with a difference of 1130 g/m^2 between the litter mass at a control site and a site exposed to equivalent heavy metal deposition (Watson et al. 1976). The simulation results pose an alternative hypothesis to the experimental inference of reduced rates of litter decomposition at the elevated levels of heavy metal accumulation (Jackson and Watson 1977), by showing that the same effect could be obtained with increased mortality of plant parts.

Next Step

The previous sections outline one particular set of models and show some simulation results including sensitivity analysis of selected parameters. The work presented is best viewe as "equipment"; the subroutines being componer parts which collectively form a package c hypotheses, theories, or knowledge in mathemati cal form. We need to thoroughly test mode through applications to experimental studies a much as possible to, hopefully, invalidate part of the model structure. The deviations of mode predictions from experimental findings provi the key to new insights - in this way mode facilitate the analysis and synthesis of compl interactions. Putting models to work in th way requires data from well-documented exper ments. For example, the uptake and physiolo ical effects of gaseous pollutants have be documented for several tree species (Jensen a Kozlowski 1975, Thompson et al. 1967, Rober 1974, Lawhon 1973, Houston and Stairs 1973), a these experimental data can be used in le physiological models (Kercher 1977) or in t models outlined in the earlier sections. A co siderable body of experimental data has be developed for air pollutant effects on plant and it is timely to apply modeling techniques the research analysis of impacts. An altern tive approach is one of conceptual extrapolati of the model behavior. Some speculations a presented in the next section.

Pollutants and the Diurnal Cycle

The modeling of water, carbon, and chemica as coupled components in soil-plant-litt systems has stimulated the development of a co ceptual framework for the diurnal cycle plants (fig. 6) that can be used to inve hypotheses of pollutant effects on who plants. In the diurnal cycle, plants chan between two <u>relative</u> states: (a) lowe sucrose, metabolite, and solute reserves at ma imum hydration (dawn state); and (b) highe sucrose, metabolite, and solute reserves at mi imum hydration (dusk state). These states a relative and apply to a given day. Photosy thesis recharges the plant with sucrose a increases starch storage (or equivalent) duri the day. At the same time, the plant is al recharging with nutrients and undergoing deh dration. The loss of water can reduce the ra of cell expansion processes during the day wi greater growth being favored with rehydratio Thus plants may need to solve a timing imbalan between carbon gain and utilization by chang in internal storage. The higher internal carb status of leaves during the afternoon may redu the significance of pollutant impacts on leav during this part of the day. Photosynthesis m be already slowed by product accumulation, alternatively detoxification mechanisms usi readily available carbon metabolites and/ energy may more easily cope with pollutant i sult than during early morning when intern carbon status is lower.

The diurnal pattern of behavior (fig. 6) al suggests that root exudation of carbon compour could be facilitated during the day. In t

ame way, the carbon supply to mycorrhizae and root nodules may be facilitated. Disruption of these processes through the impact of air pollutants may be of great importance to understanding whole plant responses. Pollutant stress that causes reduced photosynthesis and/or greater respiration in forest ecosystems may decrease the carbon leakage to mycorrhizal associations with roots, potentially decreasing the extent and efficiency of the fungi in supplying nutrients back to the tree. Thus, it may be further hypothesized that phytotoxic air pollutants may cause forest ecosystems to be less efficient in nutrient retention (i.e., become more leaky, see also O'Neill et al. 1977) and conversely beneficial air pollutants may increase nutrient retention of forest ecosystems. Elevated atmospheric CO_2 levels may be an example of the latter.

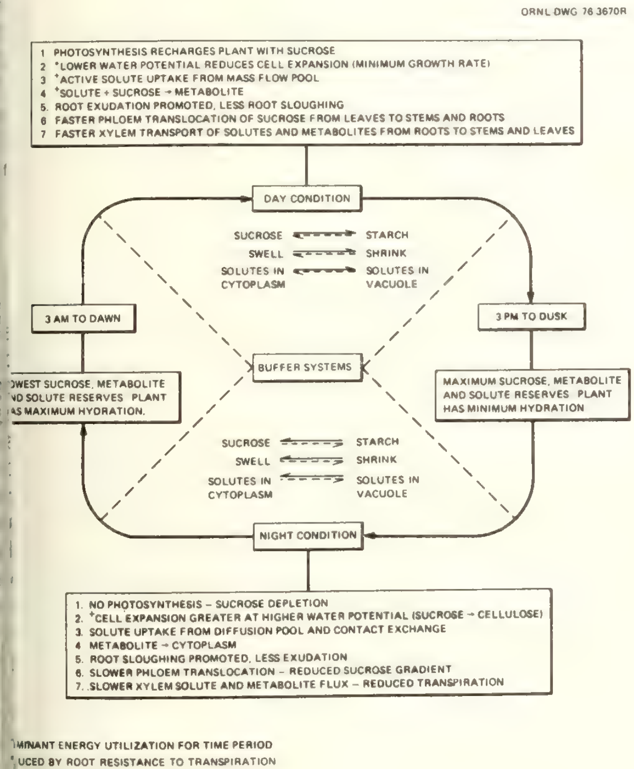

Figure 6--Diurnal pattern of carbon, water, and solute dynamics showing relative tendencies and relative states in vegetation.

Perhaps, like Humpty Dumpty, these attempts at deriving whole system understanding from the pieces involved shows many cracks and flaws. Nevertheless, we give it a go! The key test is our answer to the question "Did we learn something that we didn't know before?"

SUMMARY

Modeling of pollutant interactions with whole plant processes has provided:

1. Insights about the processes and their interrelationships, e.g.,
   (a) Transpiration may facillitate pollutant uptake by transporting chemical from roots to stem thus maintaining a favorable chemical gradient for continuing uptake.
   (b) Phloem and xylem may provide ready transport pathways for pollutant movement between plant parts (fig. 3).
2. Identification of plant properties important in pollutant uptake. In particular, leaf and root chemical conductivity have great influence on pollutant uptake (fig. 5, table 2).
3. Alternative hypotheses, e.g., increased forest litter in areas polluted with heavy metals could be due to increased mortality of plant parts in addition to reduced decomposition rate.
4. A basis for short-term (diurnal) and long-term speculation or pollutant impacts, e.g.,
   (a) Hourly changes in water, carbon, and nutrient status of plants may influence physiological sensitivity to pollutant insult.
   (b) Pollutant disruption of carbon allocation to belowground processes may have long-term nutrient cycling impacts.

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Data-Based Ecological Modeling of Ozone Air Pollution Effects in a Southern California Mixed Conifer Ecosystem[1]

Ronald N. Kickert and Barbara Gemmill[2]

Abstract: The purpose of this research was to determine the effects of ozone air pollution on a mixed conifer forest ecosystem in the San Bernardino National Forest, California.

We used an ecological systems modeling approach in concert with various biological specialists. This required conceptual model development, computer programming, and the analysis of original project data for model calibration.

We found that this process led to the investigators conducting new research of an integrative nature. A structure for complex interactions of forest effects was produced. Insights on changes in ecosystem dynamics and a worst-case scenario of future forest changes were derived.

We conclude that sudden qualitative changes in conifer forest composition can occur under the influence of ozone air pollution and the exclusion of natural fire events.

:f it were known that air pollutants did not f·ct people and their environments, society o.d be likely to have little interest in those o.utants. The central issue is "What are the f·cts?".

INSTITUTIONAL SETTING

In the United States, National Ambient Air u·ity Standards for ozone have been legally es- a·ished with a view for effects on humans, the r·ary standard, and separately for the effects on the biological, ecological, and physical environment, the secondary standard. Recently, the standards were raised from 0.08 to 0.12 ppm for one hour per year (U.S. Environmental Protection Agency 1979). In view of the fact that knowledge of pollutant effects continues to develop, the criteria for justifying the legal standard is expected to be re-evaluated every few years.

THE PROBLEM

In evaluating criteria for deciding upon the secondary standard for ozone, it has been recognized throughout the 1970's that biological and ecological effects information was biased toward the more reductionistic levels, i.e., biochemistry, plant science, plant physiology, and, because of logistical problems with larger spatial and time scales, biased against, or at least failing to consider, effects on "natural" ecological systems in the landscape. Biological effects criteria have been based on data for individual organisms, but the direct and indirect effects on plant and animal communities have been mostly speculative (U.S. Environmental Protection Agency 1978).

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[1]Presented at the Symposium on Effects of Air ollutants on Mediterranean and Temperate Forest cosystems, June 22-27, 1980, Riverside, alifornia, U.S.A.

[2]Senior Systems Analyst and Assistant pecialist, respectively, Division of iological Control, University of California, lbany, Calif.

History of The Study

Objectives of the Entire Project

In 1973, the EPA established a several-year study of oxidant effects on the mixed conifer ecosystem in the San Bernardino National Forest. The interpretations derived to date from this project have constituted the major source of information for the ecosystem chapter on air quality criteria published by the EPA; however, the majority of the data integration remains to be completed. As a further focus of the project, two years after it was initiated, the senior author was brought in to introduce computer simulation as a tool in guiding the collection, integration and interpretation of data on forest responses to oxidant stress. The potential use of this study in future policy-making required an emphasis in the modeling effort particularly on long-term effects, projected effects at different theoretical levels of oxidant flux, and effects on the behavior of the natural community as opposed to individual organisms.

Objectives of the Modeling Activity

Structural Simplification--The goal of the ecosystem modeling effort is twofold, and equally diverse in each direction. Due to the nature of the SBNF project, it was required that the modeler begin with a localized, real-world situation and make extensive use of the large data-base in constructing the model. The real world situation, from which the data are derived is extremely variable, consisting of an east-west trending mountain range which increases in elevation and changes in species composition along the same gradient of oxidant flux, such that essentially no control areas are possible. Given such a complex system, the first goal of the modeling activity was to break down this system structurally into its simplified, basic components and driving factors.

Experiments and Model Behavior-- The other half of this goal was to provide answers to the question: how might one use a simulation model for computer experiments to assess the totality of these effects, acting alone or synergistically, on ecosystem structure and function? A list of effects does not help policy makers very much when they are in the position of making decisions in the face of uncertainty - even less does it inform biologically knowledgeable people who rightfully suspect that interactions occur between items on the list that will affect future outcomes as much or more than a summary of simple effects could ever express. Thus, the modeling effort has been developed to address the following questions:

> The EPA/SBNF Project has attempted to establish effects of ozone air pollution on tree stem growth, foliar injury, tree mortality, regeneration, cone production, nutrient cycling, and insect and disease occurrence.
> What is the consequence of these effects when combined together in a simulated ecosystem?
> What time scale is necessary to use to see the full long-term ecosystem effects? Is there potential in this system for sudden jumps and irreversible trends?

The modeling methods and philosophy used in th project have been described in previous publicatic s (Kickert 1977a, 1977b, 1980).

RESULTS

Because the modeling activity is still being conducted, the results presented here are not bas on experiments performed on the computer using th models. Rather, they are based on insights gained during the model development process, from concep tualization, to mathematical formulation, to comp ter coding, and analysis of original data toward goal of calibrating the models for tree species a sites within the SBNF and then applying those mod els in experiments of air pollution effects.

How the Systems Modeling Process Aided the Projec

There are two ways in which the total study w improved. Model development aided the project investigators in viewing their own work as a part o an integrated conceptual structure. Also, with th design of a graphic model of various subsystems, discussions with investigators led to the identif cation of questions subsequently turned into research which otherwise would not have been done. A mixed tree species population dynamics approach led to seedling establishment experiments, study plot seedling regeneration surveys, and a comprehensive pest damage inventory, to determine morta ity patterns. Data needed for calibrating a stand moisture model led to a seismograph survey for pl soil depths which indicated soil water monitoring profiles were too shallow on several plots. Infoi mation required for root disease and bark beetle namics led to more cautious use of the smog injui scoring procedure, as well as to the dendrochronc logical analysis of tree radial growth.

A Structure for Complex Interactions

The effects of air pollution in the forest ec system are not only the direct visible effects that a casual observer might notice by discolorec foliage on the trees, but also less apparent, bu nonetheless real, indirect effects that are subtl transferred through the system. Such indirect cha reactions can occur at the level of individual trees, at the population level of trees of a certain species, and because of changes in the mixtu of the latter over the long-term, changes which occur at the whole community level. As a map of h such changes can be transferred throughout the sy tem, figure 1 displays some significant portions of a forest ecosystem which must be considered. reference numbers associated with each component this diagram pertain to various kinds of environmental conditions and biological organisms important to understanding changes occurring in a for t ecosystem. These numbers also reference particul

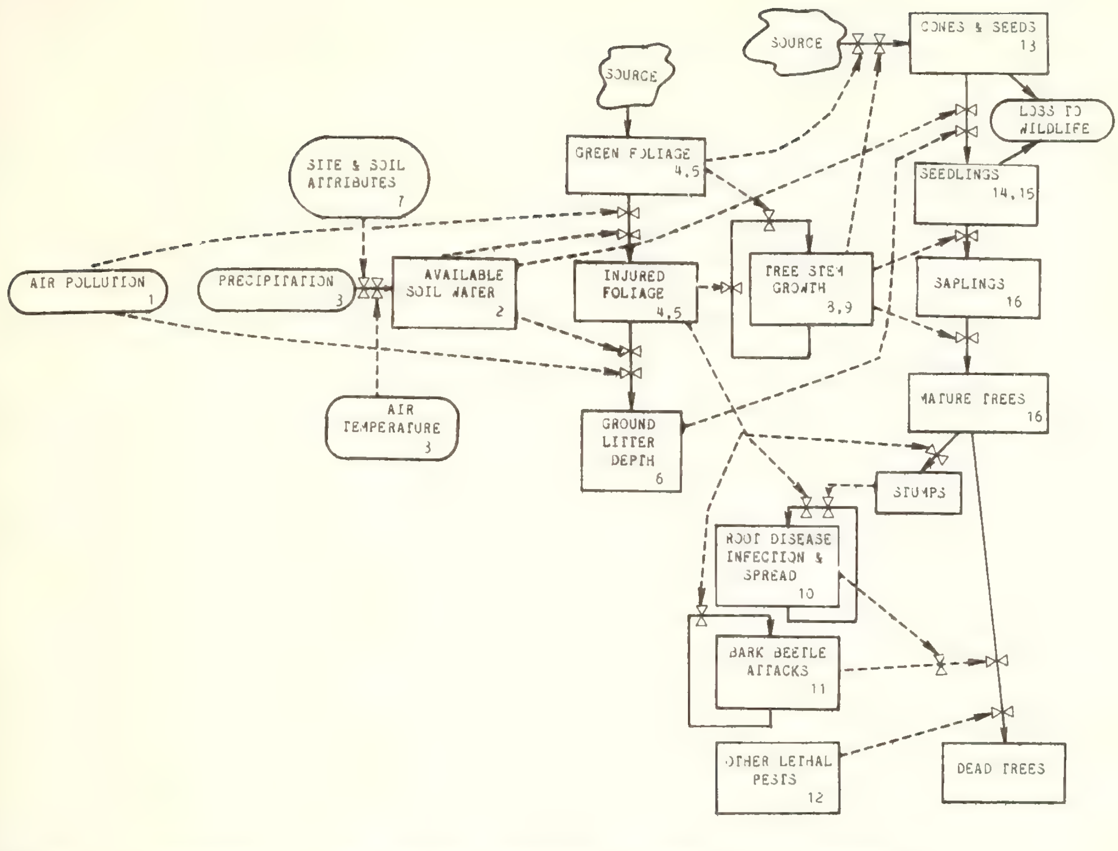


Figure 1--Components of the forest ecosystem directly and indirectly affected by photochemical air pollution.

esearch topics which have been studied between 973 through 1980 in the San Bernardino National orest.

The purpose of this overview is to present an ntegrated, simplified frame of reference within hich the discoveries, results, and conclusions from he project may be viewed as a whole.

While a forest is more than simply a group of rees, the latter is by definition the dominant ife form of such a system. Reference will be made o the numbers in various parts of figure 1. To ir the effect of air pollution (1) on a community f trees, it is necessary to consider several relaively static site and soil properties (7), as well s very dynamic meteorological conditions such as ir temperature and precipitation (3), since all of hese may contribute to a synergistic effect of a ong-term, chronic air pollution exposure in terms f tree response. Some of the precipitation (3), epending on site and soil characteristics (7), nters the soil as available soil water (2) for ree growth (8,9). For lack of better data, we envision air temperature (3) as a rough index of heat vailable for enabling available soil water to be epleted through water lost from tree leaves to the tmosphere through transpiration.

Over time, and depending on sensitivity between nd within various tree species, some of the green oliage (4,5) on trees becomes injured, discolored oliage (4,5), and some of that is dropped from the rees. This, added to normal amounts of needle shed ffected by the availability of soil moisture (2), ecomes a part of ground litter (6).

The relative amount of foliage that changes from green to injured is thought to have a bearing on the rate of stem wood growth (8,9) of trees. These three responses are thought to be associated with the rate of production of cones and therefore seeds (13) for regeneration of new trees. As pollutants lead to a greater degree of foliage injury for some tree species, and stem growth is reduced, otherwise mature individuals of these species produce less and less cones, if any.

It has been mentioned how air pollution can increase the ground litter depths (6). This is significant because seeds (13) of some tree species have a biological behavior which is adapted to little or no ground litter for sprouting and surviving as seedlings (14,15) during dry summers (the effect of available soil water (2) once again). Many cones, seeds, and small seedlings are lost to wildlife of various forms under natural conditions. Any further reduction in this reproduction chain because of air pollution effects can make continued replacement of some tree species a very precarious circumstance.

Those seedlings that do survive the first few years eventually grow to a larger size often called saplings (16) in the population structure. The extent to which the effect of air pollution retards stem growth (8,9) simply tends to keep trees in this size range for a longer time, subject to the many causes of death which can occur. Eventually, some saplings grow into larger sizes which are mature (16) and potentially capable of producing cones, as well as being valued for esthetic purposes and as

potentially merchantable timber.

Those mature trees that develop a significant degree of visible foliage injury (4,5) are sometimes cut down whether legally or by poaching. This produces stumps. It has been discovered that the degree of foliage injury (4,5), namely the younger the age of the oldest needles, is significantly correlated with the incidence of infection and colonization of such stumps by the root rot disease (10) Fomes annosus, if the fresh stumps are not treated when the live tree is first cut. One would hardly be concerned about this if it were not for the observation that such diseases can spread from dead stump root systems into adjacent live tree root systems, from seedlings, up to large, mature, pollution-resistant trees, depending on the spatial density of the stand. When this does happen with the latter, and those trees already have a considerable degree of injured foliage (4,5), then, especially on ponderosa pine, bark beetles (11) appear better able to successfully attack and kill such trees. Mortality surveys show numerous other patterns of disease and insect combinations (12) also act to kill trees. Reduced growth cannot be sustained indefinitely, and the length of time of reduced growth prior to death appears to be age-dependent.

Over time, the complexion of the forest ecosystem will change according to which tree species are best able to resist the agents that cause death (16), whether natural or human-caused, and are also capable of providing new young seedlings (14,15) able to survive to maturity. In many cases, the evidence seems to indicate that the balance between various tree species is shifting dramatically in the San Bernardino National Forest.

Given three direct effects of air pollutants on forest growth, namely foliar injury and accelerated needle cast, woody growth reduction, and indirectly increased mortality, these effects might be tied together in the following scenarios of ecosystem-level effects.

Ecosystem Dynamics Under a Single Stress

Foliar Injury Consequences-- Foliar injury and premature shedding of past year's needles will slow down the natural development of canopy closure in a stand. It has been shown and repeatedly confirmed that as a stand grows, leaf area expands until it reaches a plateau, at which it remains for the remainder of the life of the stand (Grier and others 1978) (fig. 2). Stand growth, developmental patterns and time to maturity are entirely dependent upon the rate of canopy closure. Net production by coniferous forests is related to leaf area (Whittaker and Niering 1975), and all other things being equal, the greater this leaf area, the greater is the productivity. Once maximal leaf area (canopy closure) is obtained, other ecosystem functions begin to make major qualitative changes, as discussed below. If time to canopy closure is increased, not only are productivity rates reduced, but also qualitative ecological changes may occur.

Since forest foliage always tends toward forming a continuous, complete surface area, the degree of completion represents the degree of occupancy of the site. A vigorous, healthy stand of trees will achieve occupancy of an open site at about 12 yea[rs] of age, establishing dominance over competing veg[e]tation, and will maintain occupancy until at leas[t] middle age (Smith 1962). A given generation of trees ultimately loses command of the site, givin[g] way to younger members and/or other species. A fo[r]est canopy experiencing pollution-caused injury might not be able to fully establish occupancy of the site. The amount of accompanying vegetation, especially of an understory nature, might indicat[e] the degree to which the main stand falls short of full occupancy.

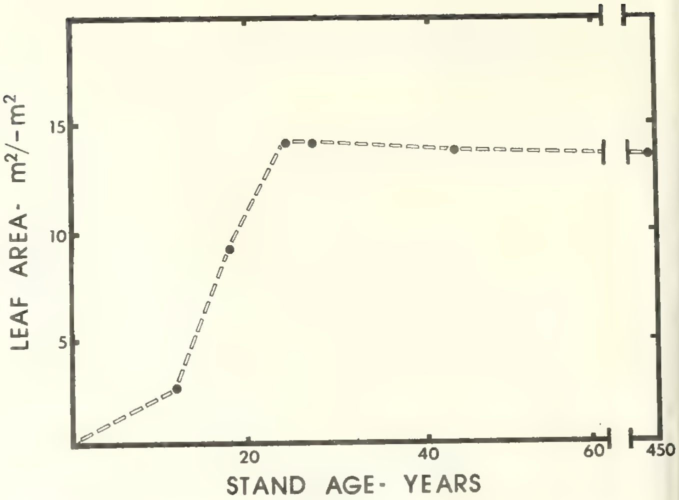
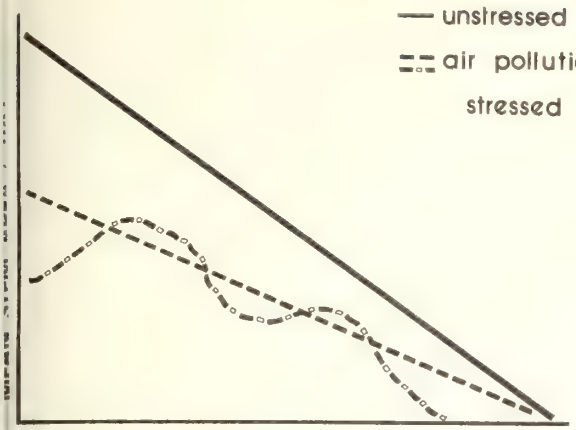


Figure 2--Natural forest stand canopy closure.

Growth Reduction Consequences-- Leaf area is dire[ct]ly related to woody production in a forest stand, as mentioned. Impediments to leaf area expansion and canopy closure might affect the overall patte[rn] of woody growth in a stand. Studies have shown th[at] second-year needles are more important in providi[ng] photosynthate for stem growth, while current year needles contribute primarily to shoot and needle elongation (Walker and others 1972); the second year needles are the most impacted by air pollution. Trees might continue to put on height growt[h] at the expense of diameter growth for a longer pe[r]iod of time than with a normally closing canopy, both because of a lack of photosynthate for stem growth and because the open canopy fosters rapid height growth rates. However, because growth and productivity is suppressed, both height and diameter growth rates in general would be much slower than normal.

It is a tenet of silviculture that changes i[n] stand density do not significantly alter the tot[al] amount of dry matter or stem wood produced by a stand. Thus, precommercial thinnings do not mark[ed]ly change production rates but rather add the sa[me] amount of wood to a lesser number of trees (Smit[h] 1962). Mathematically, mean plant size multiplied by density tends toward a constant. This relatio[n]ship has been confirmed to hold true for many ve[ge]tation types, including forest stands (Cooper 1961). In a pollution stressed forest, however, [o]ne might expect the relationship either to be weak, [or] to break down altogether (fig. 3). At low densi-



ıre 3--Relation between stand density and average e size with and without air pollution.

is, mean plant size is not remarkably large as h trees are not in good vigor; at high densities, nt size is suppressed even more than would be ected due to density effects alone. In especial-y damaged and open stands, the relationship might e expected to break down. The functioning of the ationship is dependent upon trees exerting an luence over each other. If all trees are gener-ly weakened in competitive ability, their growth l depend more on limitations imposed by the phy-al environment and less on inter-tree influences. n open stand with highly variable tree sizes might e the result.

e Mortality Consequences-- Typically, a stand of es achieves a density in balance with the physi-al environment by means of death of less competi-i trees in the stand. Thus, there is generally ntinuous decline in stand density with increas-n stand development. In a pollution-stressed for-s one finds the phenomenon of selective mortali-y However, the magnitude of the mortality can be ter and the cause is other than simple competi-i stress. As young trees prematurely age, taper f in growth, and die, more openings are created n he canopy. While in a healthy forest this pro-ies room for the dominant trees to expand, in olution-stressed forests the open canopy is open-d urther. Even if the pollution should be removed ro the system, a lower stand density because of ncreased mortality rates requires a greater time o evelop a full canopy than would a stand with a o normal stocking rate.

ontial Responses Under Multiple Stresses

Dolan and Hayden (1978) classified types of hnges in nature reserve park ecosystems as either tedy state, eddy state, or trend state. Steady te changes include diurnal and seasonal environ-eral changes under which the system has evolved. dd state changes are discrete pulses of environ-eral disturbances. Trend state changes are long-er changes that are often the most subtle to de-ec, as well as the most difficult from which to protect natural landscape ecosystems if those chan-ges are associated with human influences. Effects of air pollution on forests can have this trend state nature.

A Worst-Case Scenario of Future Forest Change-- It could be insightful to integrate the present state of ecological understanding on combinations of trend state changes in an attempt to see what a possible worst-case scenario might be for vegetation in western coniferous forests. The relative order of sensitivity, conceived as probability of mortal-ity associated with a particular environmental stress, is often different (even opposite) between various species for one stress, compared to another. Ranking tree species of mature individuals in terms of likely mortality to fire would place ponderosa and lodgepole pine as "low", while white fir and incense cedar would often be rated "high". The lat-ter would be killed by a moderate intensity surface fire (not a prescibed burn necessarily).

In contrast, research on ambient oxidant air pollution sensitivity has shown ponderosa pine as very sensitive, while white fir and incense cedar might have a low sensitivity to this stress. Air pollution weakens certain tree species which are subsequently hit by biotic diseases and insects, and produces a decreased competitive advantage, compared to less sensitive species. In the commun-ity, this can lead to decreased longevity of the sensitive species.

As a worst case condition, one could envision that our present western forest heritage from pris-tine decades ago under a natural fire frequency shifted the balance of tree species composition such that it was heavily proportioned with what are now air pollution sensitive species. If the air pollu-tion problem intensifies over the years, these species can be expected to be decimated. The combin-ed effect of both of these trend state changes, each working on different tree species, might make it impossible to preserve and protect coniferous forests in certain locations (fig. 4).

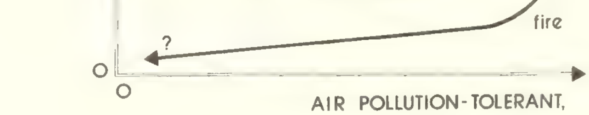


Figure 4--Possible future course of forest species composition under combined stress of air pollution and natural fire exclusion.

CONCLUSIONS

In the case of air pollution, there could be the gradual elimination of many fire-tolerant tree species from forests. Whenever a natural fire does occur under such a future scenario, the proportion of forest stand species in the fire-sensitive category could be much higher than normal, and sudden qualitative changes, or ecosystem catastrophes, in conifer forest species composition could be expected. There is a strong likelihood that conifer stands might change into mixtures of deciduous tree and shrub communities at mid-elevations, and perhaps scrub field ecosystems at higher elevations which presently contain conifer forests. This would represent a qualitative change from one successional pattern to another, and is a possibility which forest management has a responsibility to try to evaluate.

Acknowledgments:

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Response of Plant Communities to Air Pollution[1]

R. Guderian and K. Kueppers[2]

Abstract: Under the influence of air pollution two retrogressive processes are set in motion in plant communities: By means of direct and indirect effects, changes occur in structure and function of the community leading up to total destruction. Parallel to this degradation (retrogression) is a spontaneous or man initiated process during which the original adaptive resistant members of the existing community as well as new arrivals undergo secondary succession. The causes and mechanisms for air pollution-induced changes in plant communities are demonstrated by means of literature analysis and the interaction of dose response determining factors are summarized. In order to emphasize the existing potential danger and to set remedial procedures in motion, research themes are pointed out that must receive immediate attention.

Thus far research on the effects of air pollutants on plants has been centered on homotypical populations of economically important species. With the development of long-term loading of extensive areas entire ecosystems are also increasingly being influenced by air pollutants. From this, the question arises as to the possible reactions of phytocoenoses to changed air quality as a new habitat factor.

REACTIONS OF PLANT COMMUNITIES RELATED TO AIR POLLUTANT CONCENTRATIONS

Single or repeated observations in the vicinity of single sources as well as within and outside of extended regions subjected to air pollution load can only provide momentary records or sequences of changes under the respective local conditions. In general, however, certain inherent patterns of the confrontation between plant communities and air pollution may be deduced.

For the following comparative study of the influence of varying concentrations of air pollutants on vegetation, a division into the following levels, derived from Smith's classification (1974) seems practical: high, intermediate and low dosage effects.

High Pollution Dosage

A characteristic of the relationship between high dosage and the reaction of a plant community is a breakdown of community structure -- more or less obvious depending on the complexity of the ecosystem. The degradation of the system is characterized by a rapid change in structure, including composition. It is accompanied and finally replaced by a secondary succession which can lead to a new equilibrium under sustained load.

Direct acute and chronic injury appearing especially on leaves, but not always correlated with their pollutant content, (Guderian, 1970; Linzon, 1979) will first affect the most sensitive species of the tree stratum in a forest and can lead to the total destruction of the canopy. Without protection from the freely

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entering air masses of polluted air (Bennett and Hill, 1975) shrub, herb and moss or lichen layers are destroyed one after another, until a barren zone results (Gordon and Gorham, 1963; Woodwell, 1970). As an example of such conditions, the zonation under the influence of approximately 10 tons of SO_2 per day from an iron ore roasting furnace in Biersdorf (Germany) will be described briefly.

The denuded zone in the immediate vicinity of the emission source is surrounded by the transition zone with isolated clusters of grass (Deschampsia flexuosa) and resistant ground cover (Erica cinerea, Galium mollugo, Veronica officinalis, Rumex acetosa, and Convallaria majalis). Now and then one also encounters the relatively resistant Sambucus racemosa and Rhamnus frangula in this zone. In the grass cover of vegetation consisting mostly of Deschampsia flexuosa the first shoots of Quercus petraia are established in the shelter of the herbaceous vegetation. The populations of this oak and Fagus silvatica which adjoin the stunted forest zone show signs of disintegration starting at the periphery. As SO_2 loading decreases the species diversity increases, until finally it reaches the combination typical for the acidic soil-mixed forest (Fago-Quercetum).

A comparison with other studies (Treshow, 1968; Smith, 1974; Miller and McBride, 1975; and, Linzon, 1978) shows that this is the typical picture of the break-down of a plant community, that is, a change in species composition toward a simplification of the system. In principle it does not differ from that caused by gamma radiation (Woodwell, 1963, 1970). The secondary succession which sets in as soon as the original vegetation begins to change leads in time under constant loading to the formation of new, less complex stable structures. Thus, in an old manufacturing district of Upper Silesia (Poland), in locations once stocked with native coniferous or mixed deciduous forests, Wolak (1977 and 1979) described a stable zonation in relation to different loads of SO_2, zinc, and lead. Under heavy loads an industrial wasteland is followed by a grass zone with associations dominated by Deschampsia flexuosa on oligotrophic sand, by Calamagrostis epigeios on mesotrophic sites, and by Calamagrostis villosa on damp organic soil. In the adjacent shrub zone one finds both cultivated and volunteer scrub tree species. It is remarkable that Pinus silvestris can take on the shape of a creeping shrub or of a tree with branches projecting horizontally up to 5 m from the stem. These dwarf forms are no more than 2 m high at an age of 30 to 50 years. On low grade sands groups of the described Pinus silvestris forms and Solanum dulcamara were found which were not found in similar locations without the strong influence of air pollution. Those plant communities are called industrio-climax communities (Wolak, 1971). They represent spontaneous associations with relatively constant species composition which have developed gradually through industriogenous (secondary) succession, both from species present before pollutant loading as well as from new arrivals, under the combined influence of the habitat factors; climate, soil, insects and parasites-dominated by the factor air pollution.

Intermediate Pollution Dosage

Intermediate air pollution dosage conditions are ecologically significant because their subtle, direct and indirect effects on the individual species can set the stage for changes in the structure of the community with possibly irreversible consequences. In plant communities experiencing intermediate pollution dosage, interruption of growth and reproduction processes as well as impairment of the vitality of individual plants, among other factors through increased vulnerability to abiotic and biotic stress, become particularly important (Wentzel 1965; Huttunen, 1979; and Laurence, 1980).

In pine and spruce populations in the Lower Main Region (Germany), which indeed show an increased sulfur content in the leaves, but did not yet display an abnormal loss of individual morphological changes such as thin crowns coupled with shorter needles were detected in olde stands (Wentzel, 1979). Such changes occur sl-ly and only the accumulation of annual effects gradually leads to higher morbidity (Wentzel, 1980). In this context the carry-over of accumulated toxicants in the new shoots of the next growing season should be mentioned (Kelle 1978; Preston, 1979). A slight change of the horizontal structure in the canopy will influence such habitat factors as the supply of lig and precipitation for the lower-lying vegetati. Frequently, the interaction of changed soil reaction--pH--and toxicant content brings about a restructuring of the shrub and herb strata over extended areas sometimes influencing natural reproduction of woody species (Lux, 1964 Wentzel, 1971; Harward and Treshow, 1975)

Such changes in the composition of plant communities were detected through vegetation surveys caused by a complex of factors. For example, certain species were found in dense clusters, while others were evenly distributed and still others were totally absent, depending on dosage (Borgsdorf, 1960; Gordon and Gorham, 1963; Niklfeld, 1967; Ionescu, et al., 1971; Trautmann, et al., 1971). Hajduck (1961 talks about positive or negative phytoindicators, while Anderson (1966, quoted in Treshow 1968) employs the terms "increaser" or "decreaser." The concept of phytoindicators is essentially the same as bioindication with lichen or moss species (Le Blanc and Rao, 1975; Taoda, 1977; and Pilegaard, 1978). Kaleta (1972) was able to demonstrate in addition the dynamics of change of whole plant associations under the influence of magnesite.

Brandt and Rhoades (1972, 1973) took tree species of several strata into consideration in their study on the influence of limestone dust on a forest community. This method made

it possible to assess the trend of future succession, especially through shifts detected in the species diversity of the seedling and sprout data. Thus, Quercus coccinea, Quercus velutina or Tilia americana can drop out as nembers of the oak-chestnut association and Liriodendron tulipifera, Acer saccharinum and possibly Quercus muehlenbergii could become dominant species. Through this example it also becomes evident how air pollutants can influence the makeup of phytocoenoses by influencing reproduction (Wentzel, 1963; Karnosky, and Stairs, 1974; Keller, 1976).

McClenahen (1978) utilized community composition as a means to investigate changes in plant communities along a pollution gradient in the Ohio Valley (USA). In this study, an eastern deciduous forest experiencing intermediate dosages was shown to decline in species richness, evenness, and Shannon diversity index within all strata of the community, particularly in those locations experiencing the highest relative dose. Simultaneously, the similarity in composition decreased with increasing dosage. Thus, the relative importance of Acer saccharinum, a species slightly stimulated by limestone dust (Brandt and Rhoades, 1972), showed distinct decline in all strata, while the importance of Aesculus octandra increased. Opposing tendencies in density were observed in some strata. A decline in the tree and herb strata was accompanied by an increase of the subcanopy and the shrub strata. This can be attributed to better light conditions in the lower strata combined with a relative increase of herbs intolerant to shade.

Low Pollution Dosage

The effects of low dosages on vegetation lie n the border zone between the fluctuating tates of normal, i.e., unaffected vegetation n the one hand, and significant injurious efects on the other hand. Depending upon the espective pollutant, its concentration and uration of action, as well as the affected obect and the local conditions, these effects an range from increases to reductions in growth, eproductive capability or quality of plants. nder practical conditions such effects can be etected to only a certain degree of the actual ntensity. The detection limit has been lowred through the development of new exposure ystems with filtered and unfiltered air (Mandl, t al., 1973; Lee, et al., 1973; Miller, et al., 979; Shinn, et al., 1979). However, measureent of pollutant effects on plant communities ccupying large regions presents particular fficulties because the necessary pollutionree control areas with comparable soil and imate are not available.

Before detectable reductions occur in productivity or alteration of environmental contions can be observed, there are various anges that are induced at the plant biochemal, physiological or substructural level (Keller, 1974; Jager and Klein, 1977; Horsman and Wellburn, 1977; and, Raabe and Kreeb, 1979). Of course the question of how much such findings reveal about the economic and ecologic performance of a particular plant species remains of central importance here. Some of the reactions undoubtedly have no effects on the total organism; even if significant effects are found, it is very difficult to establish a causal link to the primary responses mentioned above. The possible effects of low dosage on plant communities, for example, through changes in interspecific competition, are almost totally unresolved. The filtering effects of vegetation is an important process but this topic will only be introduced here.

As shown in the Solling project (Ulrich, et al., 1978) or the Hubbard Brook study (Bormann and Likens, 1979) vegetation can filter large amounts of pollutants out of the atmosphere without showing signs of external injury or growth depression. Particulate and gaseous pollutants enter an ecosystem through adsorption and absorption mainly on leaf surfaces as well as soil and water surfaces (Hill, 1971; Bennett and Hill, 1975; and, Olsen, 1976). The specific behavior of the substance is important for the possible long-term effects of low dosage on plant communities. Pollutants which are subject to rapid decomposition such as ozone or PAN take effect through the summation of direct effects. NO_x, NH_3, or sulfur compounds can be channeled into the nutrient cycle and may destroy the balance of especially sensitive ecosystems, such as moors, through eutrophication (Porter, et al., 1972; Cowling and Lockyer, 1976). The importance of acid precipitation in this context is not yet clear (Braekke, 1976; and, Tamm, 1976). Accumulating substances such as heavy metals, represent a special danger for ecosystems (Kraemer, 1976; and Guderian, 1980). Soil samples and analyses of moss specimens have revealed that a constant input into ecosystems is offset by only a limited export, and that this is now occurring over wide areas (Huckabee, 1973; Ruhling and Tyler, 1973; and Grdzinska, 1978). Such components can also endanger the nutrient cycle (Mags, 1977 and Uba, 1977); further, they reduce the number and activity of decomposers, thereby impairing remineralization as a requirement for uninterrupted biogeochemical cycles (Taylor, 1975; and, Greszta, et al., 1979). Especially, with accumulating substances and under continuous loading, it is only a question of time before the direct and indirect effects described above begin to interrupt the structure and function of plant communities.

THE INFLUENCE OF POLLUTANTS ON THE FUNCTION OF PLANT COMMUNITIES

Changes in plant communities caused by pollutants can lead to more or less lasting impairment of economic and ecologic functions depending on the dosage. The damage to agriculture

through growth reduction, loss of quality and higher labor costs have long drawn considerable attention, but only now is an attempt being made to take the effects on performance of ecosystems into account. In this connection, an especially important question is how pollutants affect such functions of vegetation as filter effect, stabilization of climate, regulation of water and nutrient cycles, soil conservation as well as the preservation of living space for polymorphic zoo- and phytoceonoses. Extensive changes in vegetation cover are probably linked to interruption or even total breakdown of all the above-mentioned functions. For example, the function of plant communities as protection against erosion or as a factor in counter balancing excessive temperature fluctuations and the accompanying danger from light frost during bud break is considerably more impaired in areas experiencing high pollutant dosage where woods have been replaced by sparse vegetation than in unpolluted areas. Currently, to what extent intermediate and low dosages affect the functions of vegetation mentioned, can, at best, be deduced to an order of magnitude (Materna, 1980) from the known real effects on vegetation.

Causes for the Observed Responses of Plant Communities

The effects of a given pollutant on plant communities, as illustrated by several examples, are determined by: the genetically predetermined degree of resistance of the companion species (Dochinger et al., 1965; Rohmeder et al., 1965), the modifying influence of environmental conditions of resistance, and the changes in intra- and interspecific relations caused by pollutants.

Populations of certain plant species, varieties, and clones, as well as individuals within the respective populations studied, react to a given air pollution stress with varying degrees of sensitivity. In contrast to certain phytopathogenic organisms (Baumann, 1951; Grossmann, 1970), there is no absolute resistance, as demonstrated by the existence of vegetation-free zones. The schematic diagram (Figure 1) is an attempt to demonstrate which factors influence the response to air pollution stress.

Individual and Species Specific Responses

According to Levitt (1972), two mechanisms determine a plant's resistance to stress: stress avoidance and stress tolerance. In the first case the stress, caused here by a specific pollutant dose, is prevented from taking effect--it is excluded. A multitude of factors determines the resistance of a plant organism to the entry of pollutants into the cell. Morphological properties such as shape and surface structure including wax layers (Rentschler, 1973; Shriner, 1980) as well as the number, distribution, and aperture of the stoma (Meidner and Mansfield, 1968) must be mentioned. According to Taylor (1978) whose definition was taken into consideration in the corresponding section of Figure 1, stress tolerance presupposes the entry of the respective pollutant into the cell. As long as the entering substance is tolerated, assimilated or buffered, and consequently no morphological or physiological change takes place, one speaks of "strain avoidance." Abov certain intracellular concentrations, for example, after certain biochemical threshold values have been exceeded, injury occurs which is either reversible (elastic strain), such as subtle changes in photosynthetic performanc (Sij and Swanson, 1974), or irreversible (plastic strain), such as injury to leaves in the form of necrosis.

Thus, the biochemical threshold values, which characterize the transitions from strain avoidance to strain tolerance as well as from elastic strain to plastic strain, determine the tolerance of a plant. It follows that the individual response can manifest itself in terms of indifference, modification or death of the affected plant depending on the level of ambient stress, and the respective resistan

As is apparent from Figure 1, a multitude o organismal and environmental factors before, during, and after the pollutant impact is responsible for the sometimes very great differences in the "resistance series" or "resistance groups" of various authors (Stoklasa, 1923; Bredemann, 1956; Thomas, 1961; Garber, 1967; Mooi, 1974; Davis and Wilhour, 1976; Guderian, 1977). All climatic factors, for example, that regulate the number, size and aperture of the stomata (Bronte and Conguet, 1975; Hall and Kaufmann, 1975), such as light, optimal water supply, high relative humidity or adequate temperature, determine the rate at which pollutants are absorbed (Guderian, 1970; Jones and Mansfeld, 1970; McLean and Schneider, 1971).

The influence of edaphic factors is demonstrated with two examples: Copper-beech (*Fagu silvatica*) is considerably more resistant on soils with high lime content than on sandy soil low in nutrients; elm (*Ulmus campestris*) proved to be one of the most resistant species in alluvial forests, but in less suitable habitats it was one of the most vulnerable of all the deciduous species (Wentzel, 1968). This shows the difficulty in setting up generally accepted resistance series, as recent studies with various soybean cultivars under changing environmental conditions have clearly shown (Heagle, 1979a, b).

The larch serves as a typical example for changes in resistance in relation to levels of concentration (Guderian and Stratmann, 1962 Wentzel, 1963). Under high, acute SO_2 concentrations, both *Larix europea* and *Larix leptolepis* show signs of necrosis before spruc

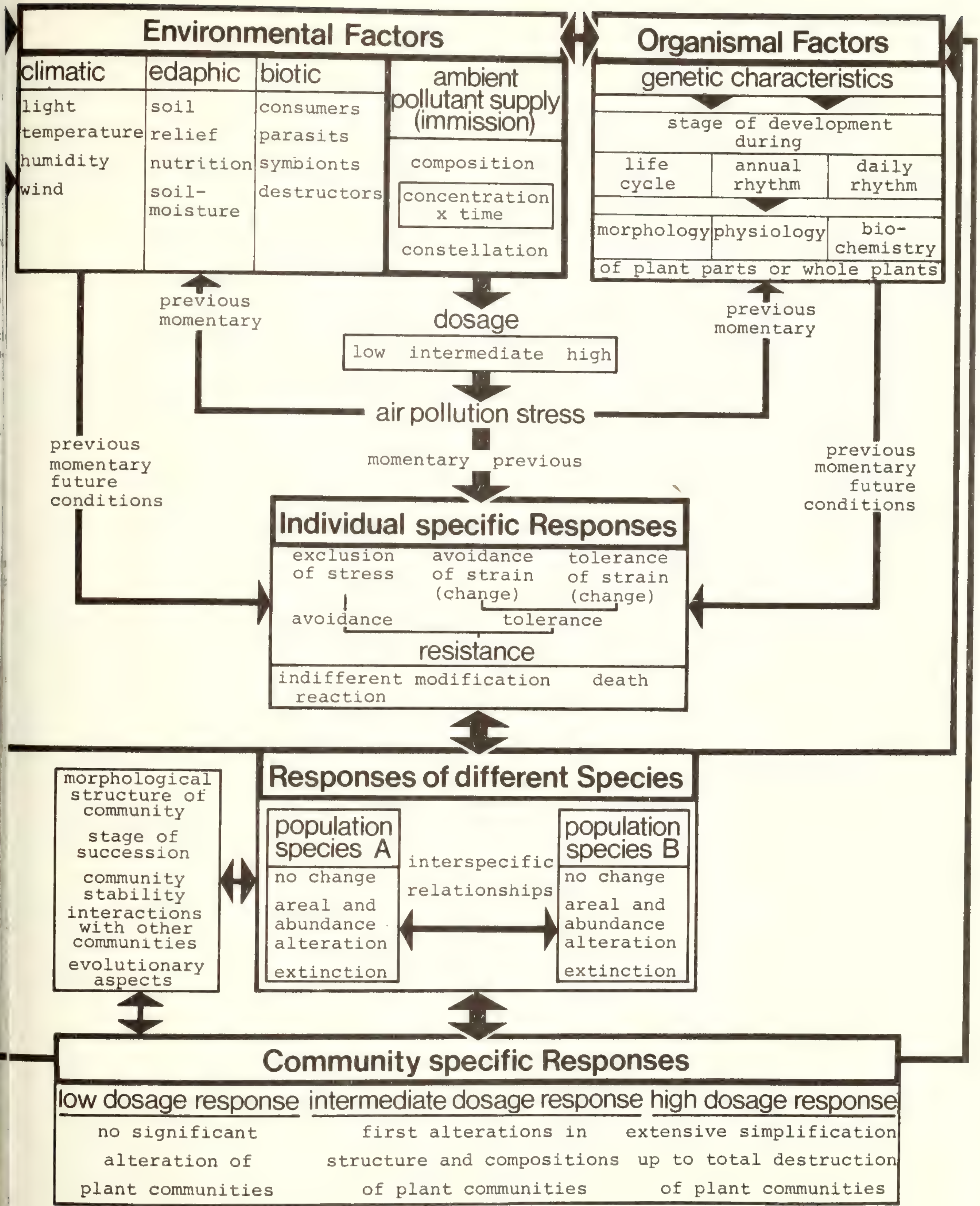

Figure 1: Effect-determining-factors for various responses of plants on individual-, species- and community-levels.

(Picea abies) and pine (Pinus silvestris). On the other hand, the larch is among the most resistant conifers under continuous low levels of concentration (Wentzel, 1963), and it is widely used to reestablish tree populations after the degradation of spruce and pine forests in regions of chronic stress.

Regarding organismal factors, the significance of age for sensitivity should be stressed. According to observation in the field, conifers such as Picea abies and Pinus silvestris remain particularly susceptible from the late pole timber stage (at the time of accumulating growth) through to the tree timber stage. During these periods of development, especially strong reductions in growth and the widespread degradation of entire stands occur (Wentzel, 1962; Materna et al., 1969), while deciduous populations respond in a much weaker form. In plantings, however, under mostly chronic SO_2 concentrations, the conifers mentioned and the copper-beech (Fagus silvatica) and pedunculate oak (Quercus pedunculata) exhibited nearly equal resistance (Guderian and Stratmann, 1968).

One aspect not often taken into account when judging the resistance of plants, besides environmental, pollutant, and organic influences, is the criteria used to interpret the effect. Various deciduous tree species, such as linden (Tilia cordata and Tilia platyphllos) and beech (Fagus silvatica) respond to acute SO_2 concentrations with leaf necrosis earlier than spruce (Picea abies) or Scots pine (Pinus silvestris). Nevertheless the deciduous species can still grow in polluted regions where spruce and Scots pine die out (Wentzel, 1968). Thus resistance must first of all be characterized by the differences in the reduction of growth and yield of the specific species. The functions of the plant species being considered here determine the criteria used to evaluate the effects (Guderian, 1977). Through the short description of factors determining the resistance of an individual or a species it can be seen what degrees of variation must be expected in the responses. The use of these results to forecast the behavior of single species under air pollution stress is necessarily very difficult, especially when studying plant communities.

In the following model, supported by experimental results, an attempt is made to illustrate the possible responses of two plant species to increasing air pollution stress (Fig. 2). A specific response of two plant species (A and B) is shown in percent of control. Up to a specific concentration labeled A1 and B3 no significant deviation in the responses of the exposed plants and the control plants could be detected. Important qualitative differences in response between the two species exist above concentration A1. With Species A, the specific response is initially stimulated by sulphur dioxide; a reduction of performance only occurs at a higher concentration, while this Species B lacks stimulating effect. The further slope of the curve shows the degree of reduction in response. The concentration A4/B4 should be emphasized, as here the resistance relationship of the two species changes (Wentzel, 1963). In the concentration range A1 to A4/B4 species A would have an advantage over species B, even under pollutant concentrations which do not yet have an adverse effect on species B. Accordingly, changes in the composition of plant communities must be expected even if SO_2 concentrations are so low that they do not yet have a direct harmful effect. This is a significant aspect for ecological research.

Community Specific Responses

The previously demonstrated relationships between heredity, environment and resistance in individuals or homotypical populations are naturally also valid for plant communities. Community specific aspects must be given additional consideration when ascertaining pollutant effects. The importance of the relationship between two or more populations shown in Fig. 1 is underlined by the few existing results from experiments on the influence of air pollutants to plant communities. Thus, according to experimental analysis of pure and mixed seedings, consisting of rye grass (Lolium multiflorum) hairy vetch (Vicia villoga) and crimson clover (Trifolium incarnatum) shifts in the composition of plant communities cannot be explained exclusively through the direct effect of pollutants on various species of different sensitivity (Guderian, 1966, 1977). Under SO_2 the influence of interspecific competition was altered. As a result, the primary effect on the more susceptible members was magnified to such a degree that they could no longer compete effectively for vital growth-determining factors. As a result of changed competition in the community, the decline of the more sensitive members allowed improved growth of the more resistant species. The total community yield decreased less than would have been expected from the loss of the more susceptible species. Similar results were found under the influence of ozone (Bennett and Runeckles, 1977), ultraviolet radiation (Fox and Caldwell, 1978) and ionizing radiation (McCormick, 1963). The last of these studies shows the importance of stress during the seedling and sprout stages.

The extent of shifts in plant communities as a reaction to a given load is also dependent to a large degree on the condition of the community itself. The importance of the building of strata, of morphological structures, as well as relief and uniformity of the vegetation cover were already pointed out as was the interconnection between stages of succession and system responses. The stability of a community greatly influences the response of its individual members as well as the whole to a given pollutant load. In the presence of small disturbances highly productive, complex systems can usually

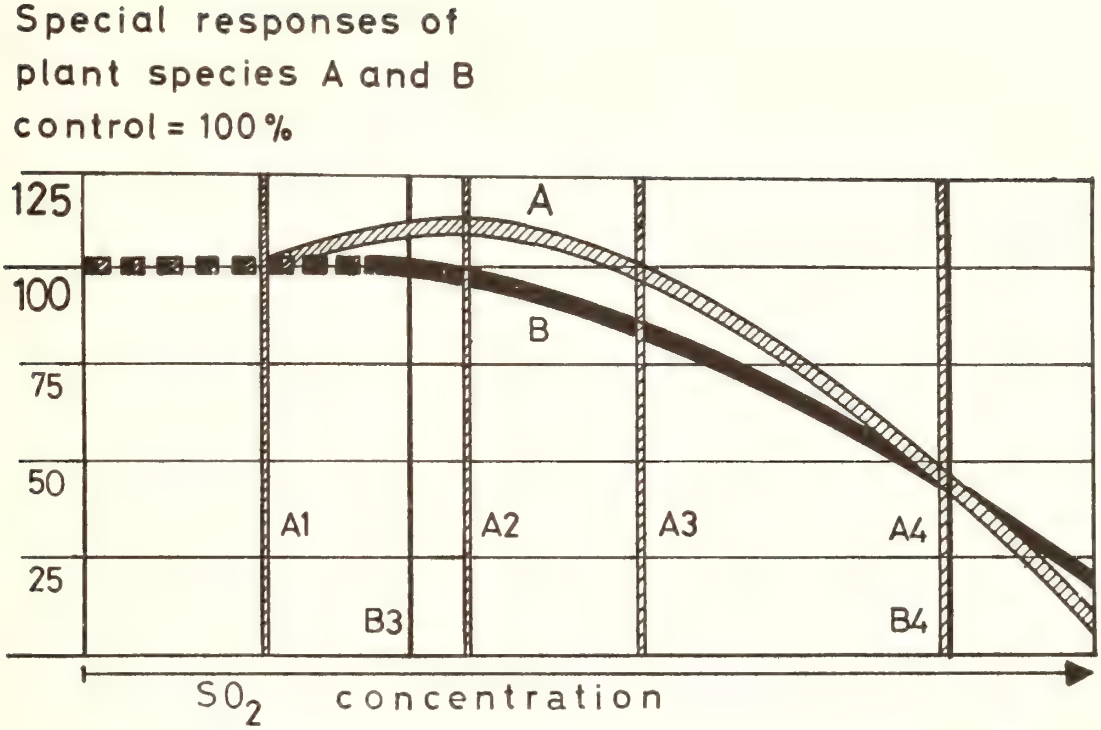

Figure 2 :

Typical reactions of two plant species depending on the sulfur dioxide content of air

regain their state of balance quickly because of their complex feedback systems. Under heavier loads on the other hand, drastic changes must be expected particularly if certain key species are very sensitive to the respective air pollutant. But even very low pollutant concentrations can produce quite considerable effects in plant communities, especially if synecological amplitudes of the natural community species are far apart. Additional stress through pollutants of lower dosage can lead to drastic reduction in vitality of plants already living outside their ecologic optimum. The relatively high susceptibility of spruce (Picea abies) in the Erz mountains (Materna, 1972) and in the boreal coniferous forests in Finland (Huttunen, 1979) might well be caused by their unsuitable habitats. Keeping this in mind, it seems problematic to transfer those dose-effect relationships determined from "production ecosystems"--in which the food plants generally encounter favorable conditions--to natural ecosystems.

The relationships enumerated up to this point show clearly why emissions induce degradation in plant communities. On the other hand spontaneous adaptation to air pollution stress may be observed--adaptation which does not ensure the survival of the species through stunting, but rather seems to have genetic origins. When Marchantia polymorpha (Briggs, 1972) was exposed to lead, and various grass species (Bradshaw, 1971, 1972, 1976) were affected by copper and zinc, more tolerant populations developed in a short time through directed selection. Bell and Clough (1973), Bell and Mudd (1976), and Horsman and Wellburn (1977) mention similar processes with Lolium perenne and Rumex obtusifolius subjected to decades of SO_2 loading. Finally, the results of long-term fumigation of native grassland (Preston and Bullett, 1978) also point to the fact that under anything less than acute concentrations spontaneous adaptation may occur in the course of the formation of a new secondary equilibrium, which may also interrupt possible long-term injury (Preston, 1979a).

Accordingly, the dose and its rate of change should be adjusted over the long-term such that plant communities retain their capability--even by the evolutionary method mentioned above--to fulfill their function in natural and agrarian ecosystems to the fullest (Guderian and Kueppers, 1979).

The genetically fixed variation in populations which is expressed in the described spontaneous adaptation, provides the basis for breeding of pollutant resistant plants through selection and reproduction of relatively resistant individuals (Bialobok, 1979).

The responses of individuals and homotypic populations taking into account interspecific relations discussed in this section, lead to the community specific responses shown in Fig. 1 which range from insignificant changes to the total destruction of plant communities.

CONCLUSIONS

Contamination of extensive areas due to increasing emissions and control strategies using tall stacks for dilution has made the study of plant communities and ecosystems especially necessary. To aid in recognition of possible risks and in making decisions regarding control measures at the source and in the affected area, the following points must be clarified:

1. Under which doses do changes occur in structure and function of plant communities of different complexity?
2. To what extent do plant communities show more sensitive responses than the individual species composing them?
3. What are the mechanisms of these changes?
   - Points of impact for air pollutants in the ecosystem.
   - Location of pollutants in the ecosystem (assimilation, accumulation, break down).
   - Direct stimulatory or injurious effects on the individual species of the community.
   - Causes and mechanisms of changes in competition equilibrium.
   - Secondary succession with particular attention to adaptation and compensation.
4. How are risks determined for plant communities?
   - Development of experimental designs and intensifications of epidemiological studies for the determinatio of effects to highly structured systems.
   - Establishment of permanent study areas to investigate succession.
   - Use of model plant communities as indicators in eco-toxicological test
   - Analysis of the condition of ecosystems before and after start-up of a pollutant source.
5. What measures are necessary for the protection of vegetation?
   - Determination of dose-response relations for plant communities as a basis for risk predictions and the establishment of standards for ecosystems.
   - Collection of genetic resources in natural reserves and in gene banks.
   - Protection of endangered plant communities, especially in existing natural reserves, from effects of air pollutants.
   - Development and maintenance of air pollutant control strategies allowing pollutant dose and its rate of change be so controlled that the structural diversity, and the ecologic and economic functions of the vegetation, as well as its function as a gene pool, are fully protected.

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Forecasting Effects of SO_2 Pollution on Growth and Succession in a Western Conifer Forest[1]

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Abstract: A simulator has been developed for the mixed conifer forest type of the Sierra Nevada, California to forecast the effects of SO_2 on forest growth and succession. The model simulates recruitment, growth, and death of each tree and is based on a northeastern USA simulator with extensive modifications. These modifications include the introduction of fire ecology, temporal seed crop patterns unique to the Sierra, and water stress. Pollutant stress is modeled as an effect on tree growth. The model simulates the shift from the ponderosa pine dominated forest type to the white fir dominated mixed conifer type as elevation increases from 5000 to 6000 ft. It also simulates the fire-suppression of white fir and the fire-climax of ponderosa pine. For a 10% growth reduction of ponderosa pine from pollutant stress and with growth reductions in other species as determined by their relative sensitivities, standing crops of ponderosa pine were reduced and white fir increased.

It is anticipated that extensive fossil fuel energy development will occur in the United States over the next several decades with increased emissions of phytoactive effluents. It has long been recognized that many of these pollutants have deleterious effects on the growth and behavior of vegetative communities. The effects of SO_2 in particular have been extensively studied and occur at all levels of resolution from the metabolic process level to the ecosystem level. In the work reported on here, we wanted to predict the effects at the population and community levels given the results of the effects at the whole plant level. We have developed other models to forecast effects at the process level (Kercher 1977; Kercher 1978). The model, SILVA, uses an empirical dose-response relationship for the effects of pollutants at the tree-level. By virtue of the ecological interactions contained in the model, the effects at the tree level are translated into effects at the community level.

We have followed the modeling approach developed by Botkin and others (1972) who developed JABOWA, a simulator of forests of the northeaste USA. For a case study, SILVA has been applied t the ponderosa pine and mixed conifer forest type of the Sierra Nevada, California, USA. The asso ciated species in these forests are ponderosa pi (*Pinus ponderosa*), white fir (*Abies concolor*), Douglas-fir (*Pseudotsuga menziesii*), sugar pine (*Pinus lambertiana*), incense-cedar (*Libocedrus* or *Calocedrus decurrens*), California black oak (*Quercus kelloggii*), and Jeffrey pine (*Pinus jeffreyi*).

MODEL DESCRIPTION

SILVA calculates environmental parameters of the stand and initializes number and sizes of th trees from environmental and control data respec tively. A table of good and bad seed crop years and a list of fire years is generated. The effe of pollution on trees is calculated. The number of new seedlings for that year, the growt of each tree, and mortality are then determined each year. Growth is modeled as a difference equation in the tree dbh and as a function of en vironmental variables. The killing is done sto chastically depending on the probability of deat as determined by ecological risk, lack of growth and fire damage. The dynamics of fuel accumulat (litter and brush) are also modeled.

Temporal Seed Crop Patterns--For the conifer of the Sierra Nevada, there can be significant temporal variations in the annual cone productio We modeled the phenomenon of high and low yield seed years as a Bernoulli random process with blocking. If the species is in an unblocked sta the probability of a good crop is p and of a poo crop is (1-p). If a good seed crop occurs, the

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process is assumed to be blocked for r-1 years. parameters p and r were taken from cone crop a.

Fire Ecology--Fire is a critical factor in the ulation dynamics of western forests. The most ortant aspect of fire is fire-induced mortality. occurrence of fire was also modeled as a noulli random process with blocking and p and re based on fire incidence data. The blocking this case arises from the time required for l to build back up to levels capable of sup- ting fire propagation. Fire kills by raising temperature inside the tree and by damaging crown. Fire intensity is calculated in kilo- ts/meter of fireline length using FIREMOD bini 1976) and probability of death is deter- ed as a function of dbh, bark thickness, and rch height. Scorch height is calculated from e intensity, ambient temperature, and windspeed.

Moisture Stress--The effects of moisture stress modeled by multiplying the difference equation growth by a moisture stress factor. Parame- s for this function are taken from published ges of tolerance data. The moisture stress tor is a function of the ratio of actual evapo- nspiration to potential evapotranspiration.

MODELING SO_2-POLLUTANT EFFECTS

It has long been held that chronic injury re- s from sulfate accumulation in plant tissues. erian (1977) has suggested that in most cases olving a single point source, chronic injury ults from the "short-term action of relatively concentration peaks". Thus the long-term rage air concentration can be quite low due to large number of pollution-free time periods. use two different perspectives exist, i.e., measuring average annual concentration or umulated dose or (2) regarding injury as aris- from episodes and making detailed measurements pisode parameters, we have two different pol- nt-effects submodels.

Seasonal Average Submodel--This approach as- s that growth reduction is a simple function he SO_2 concentration averaged over the growing on, or equivalently, of the integral of SO_2 entration over time. We use a dose-response tion in which growth decreases linearly with easing accumulated dose based on the prelimi- study of the tree-ring data of Lathe and llum (1939) for ponderosa pine grown near the ter at Trail, B.C.

Successive Episode Model--An alternative ap- ch is to calculate the accumulated damage ed by successive short episodes separated by intervals with no or negligible pollution. method to implement this approach would be to a process model (Kercher 1978). The method here is an empirical dose-response where the is that accumulated from successive episodes cher and Axelrod 1980). We use the empirical -response of Larson and Heck (1976) which models the probit of the effect being proportional to the log of the generalized dose.

SIMULATION RESULTS

Fire Ecology--Figure 1 shows the response of ponderosa pine and white fir with fire occurring at the natural frequency and with complete fire suppression. Ponderosa pine is well adapted to fire and dominates where undergrowth is thinned by fire. The model reproduces this result and indicates white fir would eventually outcompete ponderosa pine in the absence of fire. The model suggests that a significant factor in the fire adaptation of ponderosa pine is its growth rate and growth form which allow it to evade fire by minimizing the time that the crown is exposed to fire. The effects of fire on tree mortality is shown in figure 2a. Note the shift in age of death to the lower ages in the presence of fire.

Pollution Simulations--As an example of effects of pollution, consider the minimally significant case of 10% growth reduction in ponderosa pine. We scaled the response of the remaining species according to their published relative sensitivities. These calculations used the seasonal average model. The results for ponderosa pine and white fir (fig. 3) indicate that while white fir undergoes a nominal growth reduction of about 1 to 2% per tree with pollution, total basal area actually shows a dramatic increase. This is due to the much greater growth retardation that the dominant species experiences. Tree mortality of ponderosa pine (fig. 2b) indicates the trees are at higher risk at higher ages under pollution. The older, slower growing, pollution-stressed trees have size-dependent risks comparable to those of the younger unstressed trees. We can summarize (fig. 4) the results for ponderosa pine,

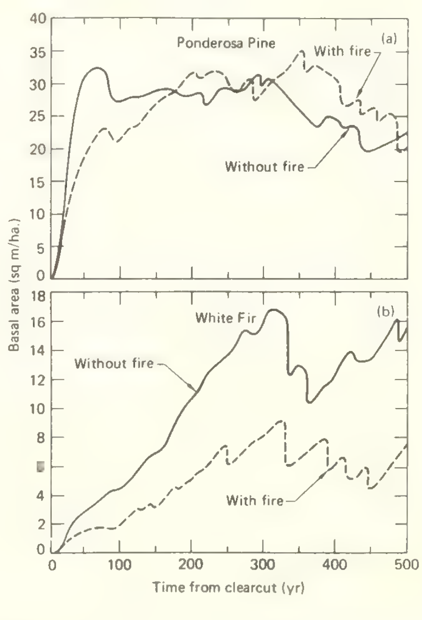

Figure 1--Average of basal area from 25 simulations showing effects of fire. (a) Ponderosa pine (b) White fir.

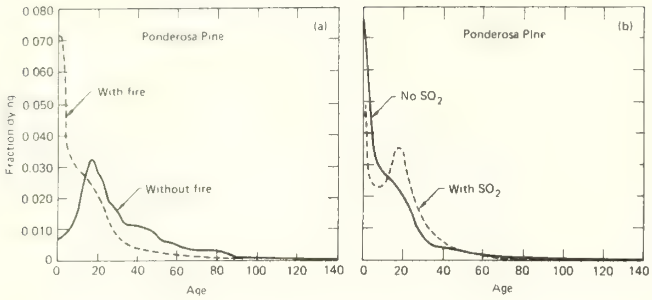

Figure 2--Fraction of trees which died in simulations of figure 1 plotted against age at death. (a) With and without fire. (b) With and without pollution.

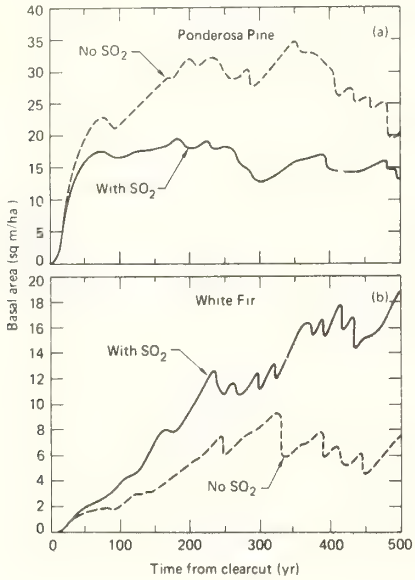

Figure 3--Basal area growth with and without pollution for (a) pine and (b) fir.

white fir, and Douglas-fir by using boxplots of the distributions of the 500 annual data points of each species fraction of the total basal area. Note the decrease in pine and the increase in fir with pollution. The basal area of Douglas-fir is extremely reduced. The environmental conditions were poor for Douglas-fir even in the absence of SO_2. The competitive disadvantage for Douglas-fir is made worse by pollution because Douglas-fir is sensitive to SO_2 and carries its needles longer than ponderosa pine. Thus the growth reduction for an individual tree (greater than that for ponderosa pine) translates into a much larger effect on basal area.

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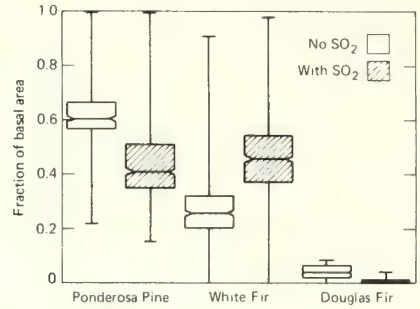

Figure 4--Boxplots of polluted and unpolluted cases. Median is line at notches. Top of box is 75th percentile; bottom of box is 25th. Range is vertical line. Non-overlapping notches indicat significance at 95% level.

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Forest Models: Their Development and Potential Applications for Air Pollution Effects Research[1]

H. H. Shugart, S. B. McLaughlin, and D. C. West[2]

Abstract: As research tools for evaluating the effects of chronic air pollution stress, forest simulation models offer one means of integrating forest growth and development data with generalized indices of pollution stress. This approach permits consideration of both the competitive interactions of trees in the forest stand and the influences of the stage of stand development on sensitivity of component species. A review of forest growth models, including tree, stand, and gap models, is provided as a means of evaluating relative strengths, weaknesses, and limits of applicability of representative examples of each type. Data from recent simulations with a gap model of eastern deciduous forest responses to air pollution stress are presented to emphasize the potential importance of competition in modifying individual species' responses in a forest stand. Recent developments in dendroecology are discussed as a potential mechanism for model validation and extended application.

Atmospheric emissions from widespread industrial and urban sources have now significantly altered the air quality of extensive forested regions of the world. Wolak (1971) described the influence of industrial emissions on forested areas of Poland as an abiotic paranatural ecological factor. He viewed the results of these emissions on forest succession as the establishment of a new final seral stage termed the industrio-climax. Assessing the impacts of these changes and those which may ensue as we rely increasingly on fossil fuels in the future is a challenge made comsiderably more difficult by the complex nature of forest ecosystems. The perennial growth habit of forest trees and the nature of their competitive interactions in a forest community make difficult the evaluation of chronic exposures of forests to atmospheric pollutants. Treshow (1970) pointed out that terrestrial ecosystems are delicately balanced with a structure that may depend on a few critical species. He indicated the response of vegetation may be slow, but once natural balances are sufficiently disrupted, subsequent alterations may occur much more rapidly because of irreversible alterations of essential system functions or species interactions.

Traditionally, studies of responses of forest trees to air pollution stress have focused primarily on species level responses, seedlings, a few selected physiological processes, and generally simplistic exposure regimes. While valuable information has been gained on specific plant-pollutant interactions, we still know very little about the potential effects of pollutants on forest communities. For instance, how are individual species effects integrated over space and time into responses of the forest community? What are the probable limits of impacts on

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forests based on our current knowledge of sensitivity of individual species responses?

To address these questions necessitates that we combine both autecological and synecological approaches. The former we can derive in large part from dose-response data for individual species. In the latter task, we can derive from the experiences of two decades of experimentation with mathematical simulation of the growth and development of forest communities (Reichle and others 1973, Munro 1974, Shugart and West 1980). The purpose of this paper is to review the basic components of these models with a view toward understanding their strengths and weaknesses and their potential utility as tools for studying community-level responses to air pollution stress.

Computer Models of Forest Dynamics

In the mid-1960's, foresters and ecologists independently began to develop extremely detailed computer models of forest growth and development. Foresters realized that certain changes in forest practice (e.g., change in trees due to genetic improvement, use of fertilizer in forests) would render less useful the stand yield tables that had been laboriously developed over the prior several decades. Some foresters began to develop models of forest growth and yield that could be calibrated on the extant, stand-table data sets and could also be used to incorporate some of the changes in forestry practice (fig. 1). At the same time, ecologists became dissatisfied with the static notion of forest typology and developed intensive investigations (e.g., the International Biological Program) of the dynamic aspects of ecosystems. This increased interest in ecosystem dynamics led naturally to the development of forest models. By the mid-1970's (fig. 1), three approaches evolved to modeling the long-term dynamics of forests (table 1). We will discuss the utility of each of these approaches in terms of its applicability to assessing the consequences of air pollution effects over long time scales. The approaches are:

(1) Forest models consider the forest as the focal point of the simulation model. Forestry yield tables constitute a highly data-dependent subset of these forest models.

(2) Tree models take the individual tree as the basic unit of a forest simulator. The degree of complexity ranges from simple tabulation of the probabilities of an individual tree of one kind being replaced by an individual of another kind to extremely detailed models that include 3-dimensional geometry of different species at different sizes.

(3) Gap models dynamically simulate particular attributes of each individual tree on a prescribed spatial unit of relatively small size. The spatial unit is usually either a gap in the forest canopy or a sample quadrat.

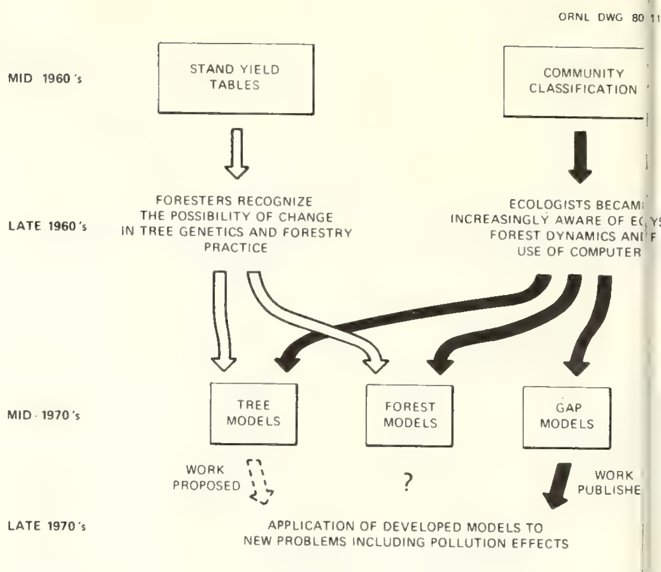


Figure 1--Recent historical origins of computer models used for pollution effects assessment at the forest ecosystem level.

In general, the model type used is based on the problem considered, the data available, and the desire to develop a flexible model. The tree and forest model categories correspond to the tree and stand model categories used in a recent review of forestry models (Munro 1974). In the present review, gap models (which might be considered a special case of three models) are recognized as a category developed exclusively for use in studying ecological succession.

Forest Models

Yield tables used in forestry management are, in fact, empirical models of expected responses of an even-aged forest of (usually) a single species. In this context, a forest is taken as a larger spatial dimension than either single tree or gap models considered explicitly.

Comparable succession models have been developed using a variety of mathematical approaches. Most of these models consider the landscape to be composed of a number of mosaic elements that change in response to successional processes. These changes may be viewed as probabilistic (e.g., Wilkins 1977, Hool 1966) or continuous (Shugart and others 1973), depending on modeling assumptions relating to the actual size of the landscape considered. Forest models tend to be data-dependent concerning changing rates of the mosaic elements assumed to compose the forests, and the actual mechanisms that cause the changes in the forests do not appear explicitly in the models. All of the forest models listed (table 1) require little computer time and can be solved analytically in many

Table 1. Classification and characterization of forest simulation models as tools for evaluating stress effects.

Model ategory	Age-structure	Space	Examples	Assessment potential: Limitations	Assessment potential: Advantages
orest	Even (usually)	Nonspatial	Most yield tables in use in forestry today	1. Usually calibrated on long-term data sets on many different sites. Slow to develop.	1. High degree of realism because of data input. 2. Familiar to the forestry industry.
	Mixed	Nonspatial	Hool 1966 Olson and Christofolini 1966 Moser and Hall 1969 Shugart and others 1973 Johnson and Sharpe 1976 Wilkins 1977	1. Usually requires data or insights that are collected over a long time period.	1. Provide a regional inventory of effects. 2. Mathematically simple and could be coupld with economic models.
ee	Even	Spatial	Newnham 1964 Lee 1967 Mitchell 1969 Lin 1970 Bella 1971 Hatch 1971 Hegyi 1974 Lin 1974	1. Require extremely detailed growth data and other detailed parameters. 2. Commercial forests only are considered. 3. Establishment may not be considered.	1. Tremendous detail. 2. Economic variables (e.g., board feet, products) simulated directly.
		Nonspatial	Clutter 1963 Curtis 1967 Dress 1970 Goulding 1972 Sullivan and Clutter 1972 Burkhart and Strub 1974 Solomon 1974 Clutter 1974 Elfving 1974	1. Require extremely detailed growth data. 2. Commercial forests only are considered. 3. Establishment may not be considered.	1. Economic variables (e.g., board feet) simulated directly. 2. Fast computationally; could be interfaced with economic models.
	Mixed	Spatial	Adlard 1974 Arney 1974 Ek and Monserud 1974 Mitchell 1975	1. Detailed data requirement. 2. Computationally slow.	1. Tremendous detail. 2. Have been proposed for use in long-term pollution assessment.
		Nonspatial	Leak 1970 Bosch 1971 Namkoong and Roberts 1974 Forcier 1975 Suzuki and Umemura 1974 Horn 1976 Noble and Slatyer 1978 Waggoner and Stephens 1970	1. Lack of detail in output. 2. Require clever validation procedures.	1. Models have been explored for their theoretical aspects. Level of abstraction is both an advantage and disadvantage.
	Mixed	Vertical	Botkin and others 1972 Shugart and West 1977 Mielke and others 1978 Tharp 1978 Shugart and Noble 1980 Shugart and others 1980 Doyle and others 1980	1. Spatial in the vertical dimension only. 2. Require clever validation procedures.	1. Have been used in long-term pollution assessment. 2. Complex parameters can be inferred from ecological principles.

ses. All of these models could be used for sessing the consequences of some inferred llution effect on a region's forests assuming at the primary problem of estimating the fort stand response could be overcome.

Spatially Explicit Tree Models

Two categories of models in table 1 (evened or mixed age) are used almost exclusively sophisticated evaluations of planting, spacing, and harvesting schemes in commercial forests. These models produce information used primarily by large governmental or industrial land managers which is as a consequence, normally communicated by direct means that do not necessarily involve the scientific literature (e.g., internal reports). The models we listed in these categories (table 1) are probably only a subsample of such models that are actually in use.

These models function by incrementing individual trees (usually tree diameter, crown volume, and various form and shape parameters) periodically and are usually solved in 1- to 5-year time steps. To illustrate the degree of detail used in such models, Mitchell's (1969) model of white spruce (Picea glauca) uses branch-pruning of trees that overlap to determine competition interaction.

The models explicitly consider the crowding of trees and can be easily adapted to either even- or mixed-age stands. In fact, Hegyi's (1974) even-aged model is derived from Arney's (1974) mixed-age model, and Mitchell's (1969, 1975) models are derived in the converse manner. The models are designed for commercial forestry operations and do not include phenomena that ecologists would expect in a succession simulator. They generally ignore establishment of invading seedlings and often use functions for geometry of trees that could only be expected to hold in young, vigorously growing trees. The models sometimes use thinning or harvest as a surrogate for mortality. Because of the level of detail needed, these models synthesize great amounts of autecological data that are usually only available for commercial species and are difficult to extend to mixed-species forests. Nonetheless, the FOREST model (Ek and Monserud 1974) does simulate mixed-species, mixed-age northern hardwood forest in Wisconsin. This model is also being considered for use in a pollution effects assessment problem (fig. 1). There is also a potential to apply the other models of the commercial species that should be explored.

Even-aged, Nonspatial Tree Models

Even-aged, nonspatial models have been used in commercial forestry also and are logical nonspatial alternatives to models in the previous category. Nonspatial models have been used almost exclusively in pine (Pinus spp.) plantations and are usually in the form of differential equations with basal area, stocking density, and volume (biomass) of a forest stand changing with respect to time. Because these relationships are functions of the size of the average tree, the models contain parameters derived from the expected growth of trees. The even-aged, mono-species character of the simulated forests allows the assumption that mathematical functions for the expected response of an average or typical tree are sufficient to express these relationships among volume, stocking, and basal area. These models work best if the trees tend to be the same size, which helps to explain the use of these models in the more genetically optimized, short-rotation, crop-like Pinus plantations. The underlying assumptions of these models limit their applications to even-aged stands, and the development of mixed-aged models using this approach is difficult. Unlike the spatial mono-species models we discussed previously, these models can, in some cases, be solved analytically and, in all case require only a moderate amount of computer time

Mixed-age, Nonspatial Tree Models

These models simulate ecological successi in naturally regenerated forests. Their emph sis is on birth/death processes affecting ind vidual trees, and the importance of tree grow and form is greatly deemphasized. They are n particularly complex (i.e., birth and death trees might be treated as simple stochast processes; replacement of trees as a first-ord Markov process), but frequently it is the stat objective of the authors to attempt to captu the salient aspects of succession with a minim model representation. In this objective, t models are actually explorations into the co sequences of theories and assumptions on t nature of ecological succession based on t attributes of the species involved (Gleas 1926, Drury and Nesbit 1973).

The models can provide considerable insig into patterns of ecosystem dynamics and can solved analytically without resorting to digit computation. An example of this modeli approach (Noble and Slatyer 1978) uses the vit attributes of species to determine the expect patterns of community successions generated competition among the species. Vital attribut considered are the modes that a species uses persist at a site, the modes for establishmen the availability of a method or persisten (e.g., seeds, vegetative sprouts) at differe life stages of the plants (propagule, juveni mature, extinct), and longevity of individual. Using these species attributes, they constr schematic diagrams of changes that can be co pared with observational data from a given area

Gap Models

Gap models simulate year-to-year changes diameters of each tree on a plot of known ar. These models do not account for the exact lo tion of each tree but use tree diameters determine tree height and then use simula leaf area profiles to devise competition re tionships due to shading. These models spatial in the vertical but not the horizon dimension. This simplification greatly redu the cost of running these models and also eli nates the consideration of complex spatial p terns of trees, should this be important in a given application. The vertical gap models probably best used in studies of successio dynamics of natural forests considered over l time spans. Gap models have also been the fi detailed succession simulators applied to pollution effects research.

Current Model Applications

Most models built strictly for forestry are usually intended as applications in a restricted set of specified circumstanc

iven the great specificity of the models, they till simulate commercially important forest ypes, and it is unfortunate that they have yet ɔ be used in any pollution effects studies. everal of the succession models presented in able 1 have been used in evaluating environ- ental impacts on naturally occurring forests. otkin (1973, 1977) considered the effects of)$_2$ enrichment on plant growth and subsequent ffects on forest dynamics. He found that an bitrarily assumed percentage change in rate of hotosynthate production at the individual plant evel in CO_2-enriched atmospheres was not anifested directly as a change in forest owth. Other effects such as plant competition d shading tended to lower the magnitude of the ystem response. McLaughlin and others (1978) d West and other (1980) performed model periments on chronic air pollution stress pressed as a change in growth rates of llution-sensitive trees. They noted that the sponse of growth over the long term and in tural forests might vary in direction as well in magnitude from what one might predict from boratory or greenhouse studies. Kickert (this mposium) and Kercher (this symposium) have so used these gap models of western forests to vestigate long-term pollutant effects. All of ese studies identify a common problem; namely, natural forests where trees vary in spacing, ze, and competitive responses, one cannot trapolate directly from laboratory studies to eld conditions. Forest succession models can ovide and have provided a necessary adjunct to boratory-based assessments of environmental fects. We will provide a detailed example of ch an application in the following section.

Gap Model Application

As used in the following example, the model he FORET model, Shugart and West 1977) con- ders 33 forest tree species native to the uthern Appalachian region and simulates growth individual trees on a circular 1/12-ha plot. e growth of each tree on a plot is incremented arly as a function of (1) total annual growing gree days (5.6°C base), (2) the total leaf ea of taller trees on the plot, (3) total num- r of trees on the plot, and (4) the size of e tree. A typical simulation is illustrated figure 2.

The selection of a species for the plot and sequent initiation and growth of the tree are sed on silvicultural characteristics of each ecies. These characteristics include:
) site requirements for germination,
) palatability of seedlings for browsers,
) sprouting potential, (4) shade tolerance,
) germination and growth temperature require- nts, (6) inherent growth potential,
) longevity, and (8) sensitivity to crowding ess (fig. 2). The initial trees established a plot with bare soil are those having shade- olerant growth requirements and germination finities for mineral soil. As the simulation

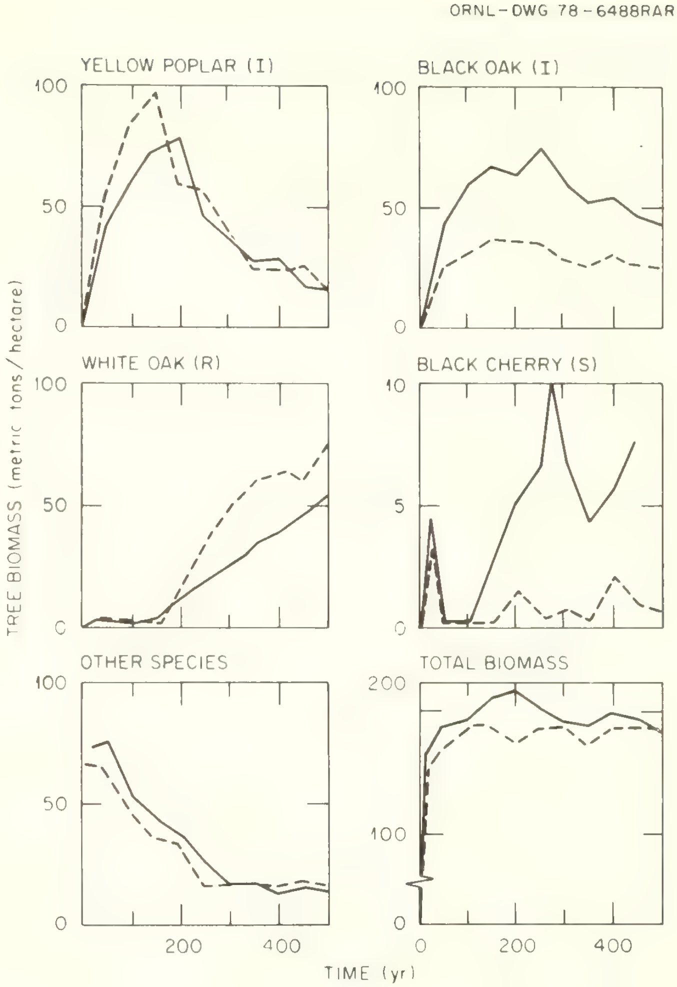


Figure 2--Species and stand dynamics of a forest with and without continuous exposure to air pollution stress (_____ unaffected; ----- affected).

proceeds, trees that have the ability to germinate in leaf litter and grow under shaded conditions are selected by the model. Leaf litter is assumed to have accumulated to a level commensurate with the total tree biomass for the plot. The amount of shade cast by each tree is a function of leaf area of the tree and is calculated allometrically from its diameter by totaling the leaf area of all taller trees on the plot. Under optimal conditions, tree growth is assumed to occur at a rate that will produce an individual of maximum recorded size (dbh) for that species during the period of maximum recorded age and is based on a curcilinear function that grows a tree to two-thirds its maximum dbh at one-half its age. Modifications reducing this optimal growth are imposed on each tree by some additive combination of shading and crowding from other trees on the plot and the stochastic variation from optimum climate. Optimum climate is defined as the means of the minimum and maximum growing degree-days within an individual species range. Death is a stochastic process with the probability of dying inversely related to the yearly growth increment. Total

stand density characteristics are calculated from dbh. Ingrowth occurs by germination of seeds and sprouting, and simulation may be initiated either from a bare plot or an existing stand of a predetermined composition and structure.

Validation of the FORET model was accomplished by simulating a deciduous forest stand with and without American chestnut as a viable species (Shugart and West 1977). Simulations with chestnut removed produced forests of similar composition to the contemporary, post-chestnut blight forest. With chestnut included, the model produced a forest similar (Spearman rank correlation - r = 0.83, see Siegel 1956) in composition to the relatively undistrubed southern Appalachian forest which existed around 1890 to 1910. All simulations were typically repeated for a large number of plots (≥ 100), and interpretations were based on average biomass of individual species and the forest stand determined from the multiple runs.

By utilizing this type model, we investigated the results of the interaction of forest tree competition and air pollution stress. In doing this, the following relevant questions concerning the response of forests to a pollutant were considered:

(1) What level of air pollution stress would be required to significantly alter forest growth and development?

(2) How are stress effects integrated over time?

(3) How important is competition in moderating or enhancing induced stresses on individual species?

(4) How are species responses integrated into the response of forest systems?

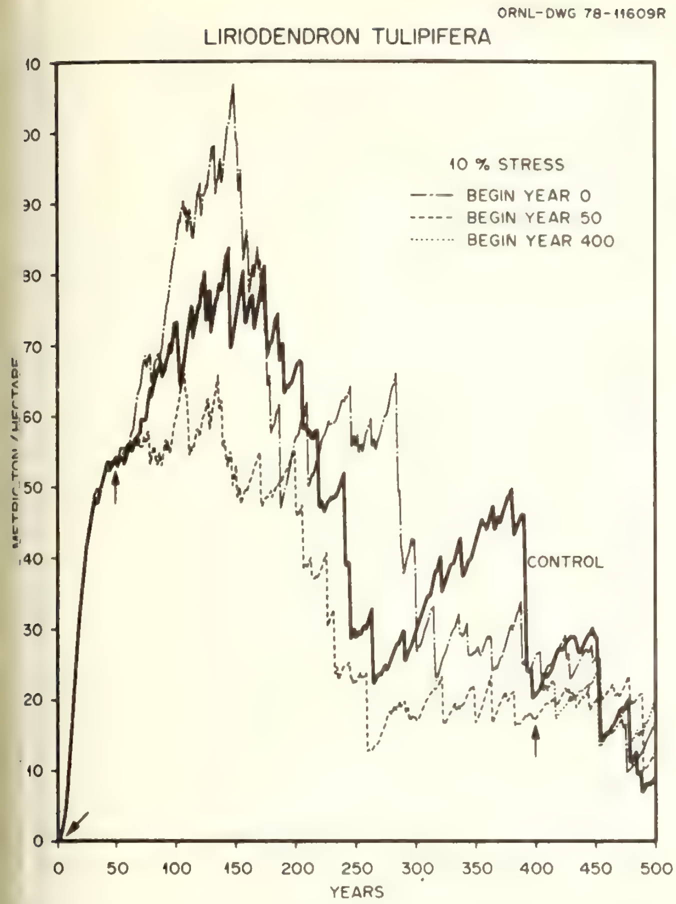
Application of the model to the study of the effects of air pollution stress on growth and development of eastern forests necessitated (1) developing a rationale for classifying species in terms of their relative sensitivity to this stress and (2) incorporating growth reductions into the model which reflected species' sensitivity ranking and a range of impacts which might be expected under field conditions.

Addressing the first task assumes that species vary measurably in their growth responses to chronic air pollution stress. Such a conclusion is intuitively obvious from a wealth of data from controlled laboratory and field studies where obvious differences in sensitivity of foliage to visible injury from air pollution have been demonstrated. Data on relative sensitivity of forest trees to growth reduction from chronic air pollution stress are limited, however. In this application, we made the assumption that trees most sensitive to foliar injury would also be most sensitive to growth inhibition. We group the 32 species into 3 sensitivity classes (resistant, intermediate, and sensitive), based on their relative sensitivity to visible injury. The sensitivity classification was based on 10 years of field survey data of vegetation near a coal-fired electric plant (McLaughlin and Lee 1974) and an extensive summary of field and laboratory data on susceptibility of woody plants to SO_2 and photochemical oxidants reported by Davis and Wilhour (1976). This classification then formed a framework for addressing the second task, determining appropriate levels of growth reduction to introduce into the modeled forest. For eastern forests, this task must also rely on the rather limited data currently available from the literature. However, one advantage of mathematical models is that a range of stress levels may be simulated. While not providing exact quantitative answers, such an approach does permit one to bracket the range of likely responses based on the best available data.

In the FORET approach, both the influence of varying stress levels and the stage of forest maturity at which stress was initiated were examined. Results of a typical simulation are presented in figure 2. Here, responses of selected species are shown from a simulation in which annual growth inhibitions of 20, 10, and 0 percent were imposed on seedlings in sensitive, intermediate, and resistant sensitivity classes, respectively. Increases in biomass of 4 major species [yellow poplar (intermediate), white oak (resistant), black oak (intermediate), and black cherry (sensitive)], the collective "other" species category, and total stand biomass were compared with and without simulated air pollution stress as the forest developed over time.

The results indicated that competition within the forest stand may greatly modify responses predicted from individual species' sensitivity to stress. Both enhanced growth suppression (black oak and black cherry) and reduced suppression (yellow poplar) were demonstrated. These responses were attributed to shifts in the competitive potential of these species induced by differential stress applied within the forest stand. An examination of total biomass of all species indicated that suppression could be greater than (as high as 20 percent) or less than ($<$ 5 percent) that of the weighted average suppression (7 percent) imposed in the simulation.

Another useful capability inherent in simulation approaches is that variations in stand age and, relatedly, stand composition may be introduced for the time of stress initiation. In the FORET test, stage of stand development was also identified as an important modifier as shown in figures 3 and 4. Yellow poplar, a fast-growing, shade-intolerant species which showed growth stimulation when the seedling forest was stressed (initiation time - year 0),



Fjure 3--Response of yellow poplar (Liriodencon tulipifera) to a 10% reduction in growth. Gowth reducing stress is applied at year 0, yar 50 or year 400.

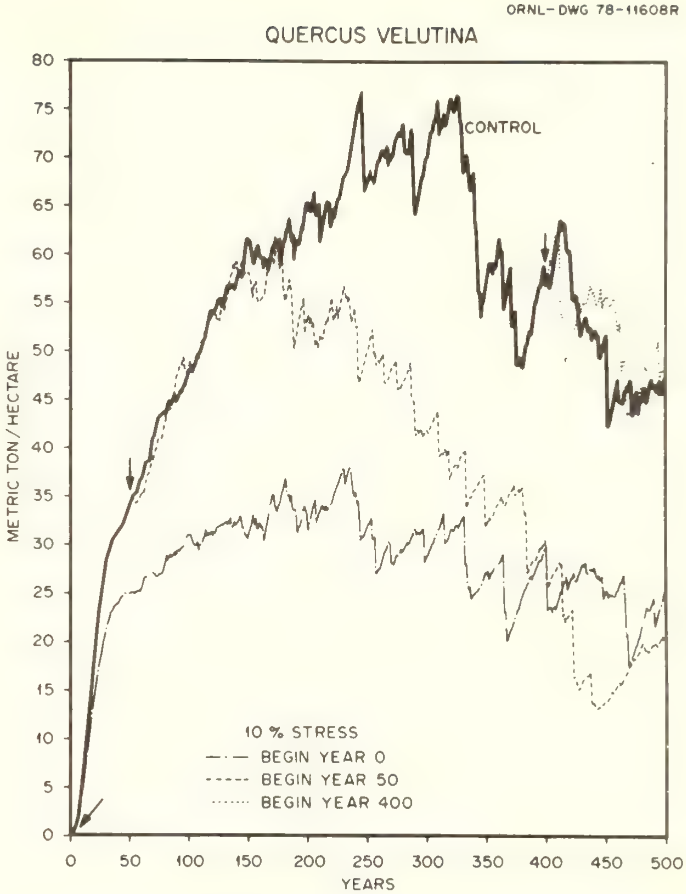


Figure 4--Response of black oak (Quercus velutina) to a 10% reduction in growth. Growth reducing stress is applied at year 0, year 50 or year 400.

sowed growth reduction in the more mature frest (initiation time - year 50) where other secies compete more favorably in the closing frest canopy. Black oak, on the other hand, wen stressed in the seedling forest showed a geatly enhanced growth reduction. When stress w; initiated at year 50, however, the response w; greatly delayed until other more resistant secies such as white oak began to dominate (see fj. 2).

The effects of differential levels of sensitivity on growth and competition of forest tees which we have shown in figure 2 are supprted by the field responses of deciduous trees misured by Brandt and Rhodes (1972, 1973). In tir studies of the effects of 25 years of liestone dust deposition on a deciduous forest, ty found changes in composition, with ireased dominance of yellow poplar, white oak, a red oak at the site of heavy dust accumulatin. Reduced lateral growth ($\geq$ 18 percent) of ssitive species such as red maple, chestnut o, and red oak was accompanied by a 76 percent irease in lateral growth of yellow poplar at t test site near the limestone quarry (Brandt a Rhodes 1973). Evidence of the amplification o effects of abiotic stress by both inter- and ira-specific competition has also been demonstrated by Fox and Caldwell (1978) in studies with UV-B radiation. In situations of severe mutualistic competition, some species showed improved growth under the UV-B treatment, a response attributed to improved competitive status. Other examples of changes in plant competition under air pollution stress were reviewed by Guderian and Kuppers (1980) in the preceding paper in this session.

Validation of Forest Community Response to Stress

While the validity of model results may be readily checked against actual growth and development patterns of "normal" forests of a region, evaluation of responses of disturbed forests becomes a much more difficult task. It implies developing a capability to clearly distinguish differences among measured values of parameters of stand growth and composition and those which would have occurred in the absence of pollutant stress. Accomplishing this necessitates either obtaining measurements on comparable stands over a variety of stress levels or documenting the growth characteristics of the stand in question before the stress was initiated. In either case, the investigator is faced with measuring pollutant effects in the face of the wide variety of biotic and abiotic variables controlling

growth of individual trees and forest communities.

Historically, documentation of forest responses to rather high levels of gaseous pollutants, primarily SO_2 and HF, from smelting processes was facilitated by the typical occurrence of well-defined gradients of stress with distance from the source. Gordon and Gorham (1963), for instance, were able to measure increased numbers of higher plant species along a 63-km gradient from the smelters at Sudbury, Ontario. These changes followed a generalized pattern of replacement of more highly evolved species of later successional stages by the more broadly adapted, stress-tolerant generalists which Woodwell (1970) reported following point-source radiation stress of a deciduous forest community.

Present-day air pollution stress regimes can generally be characterized as induced by generally lower levels of pollutants contributed by multiple sources. High-level point sources have been largely replaced by area sources where local topography and meteorology combine to concentrate multipoint effluents. Classic examples are the Los Angeles Basin in the West and numerous industrial corridors along river valleys in the East. These areas provide good possibilities for examining species and community responses to chronic and occasionally acute stress regimes.

Community-level effects of oxidants on forests of the San Bernardino Mountains near Los Angeles were described originally by Miller (1973) and have formed a basis for a broadly based study of a variety of ecosystem processes at this site. Kickert and Gimmel (1980) used these data in parameterizing a forest simulation model to describe these changes. In the East, McClenahen (1978) examined 7 deciduous forest stands located along a gradient of chronic air pollution stress on a 50-km portion of the heavily industrialized Ohio River Valley. Species richness, evenness, and Shannon diversity index were generally depressed for both overstory and understory layers in the forest as proximity to industrial air pollution sources increased. Stem density in the overstory decreased, while lower strata showed increased abundance of species along this same gradient. Shifts in relative species' importance were also noted.

Studies of the latter type provide very valuable data for describing the types of changes that may occur under moderate pollution stress, but are limited in their utility for predicting rates of change over time or at varying stress levels. Information of this type may be contained in the chronology of tree growth at that and other sites, however. Recent developments in tree-ring analysis provide a potentially powerful tool for analyzing both the rate and direction of within-community changes.

Dendroecology is a discipline of dendrochronology, the science of dating annual growth rings of woody plants (Fritts 1971). It can be considered a companion tool with dendroclimatology to examine changes in tree growth in relation to local and regional environment. The basic concepts, applications, and limitations of dendroecology have been discussed by Fritts (1971). In general, it relies on multivariate statistical analysis to identify principal variables influencing tree growth. Resultant equations are in themselves models of individual tree growth over time. As a tool for studying air pollution effects, dendroecology permits separation of effects of tree age and local climate from those induced by air pollution (Nash and others 1975). Phillips and others (1977a,b) have used this approach to correlate growth reductions in stands of loblolly and white pine with production levels near an army munitions plant. More relevant to the challenges of providing reliable predictions of species and community-level changes is the potential utility of this technique for detecting growth responses in our eastern regional environment. Measurements of growth reductions of white oak in apparent response to chronic stress of this type have been reported near LaPorte, Indiana, by Ashby and Fritts (1972). In this case, the decade during which anomalous growth reductions occurred was associated with a heavy incidence of smoke and haze in that region.

Documentation of pollutant histories in the broader regional context represents a more difficult task but one of great importance to efforts to eventually develop a predictive potential. A greatly expanded network of air quality trends; however, data for the past 40 years, during which emissions in the Eastern United States increased sharply, are lacking. One potentially useful tool for obtaining histories of exposure to general air pollution stress is heavy metal analysis in the individual rings (Lepp 1977). This approach has been used in Sweden (Symeonides 1979) to construct histories of heavy metal pollution, although Tian and Lepp (1975) caution that factors such as radial transport and soil uptake must be fully understood to use this technique accurately. In the Swedish study, both lead and copper showed little lateral movement and were useful in constructing a decade-level history of metal pollution at the study site. Recent developments coupling x-ray emission spectroscopy (Valkovic and other 1979) with growth-ring analysis show promise for using a variety of trace elements for historical analyses. As these techniques are developed further, they may provide useful data for constructing historical indices of regional-scale chronic stress.

The tools for validating or modifying forest simulators as predictive tools appear to be either available now or close at hand. We feel that dendroecological approaches have tremendous potential for unlocking a wide variety of

pecies/community/environment interactions which ill make this task ultimately possible. Probably, the greatest value of the forest simulaors is in predicting the consequences of sets f "most logical" assumptions regarding pollution effects on trees. Other assumed relationhips can be tested easily, and new information ay be added as it is developed (Kozlowski 980). The model is merely a tool to be used in his synthesis and refining process.

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ynthesis Session

Opening Remarks and Summary of Panel/Audience Discussion[1]

Walter E. Westman[2]

Abstract: In the opening remarks by W. E. Westman, three major questions were raised: (1) How can resilience of ecosystems to air pollution damage be predicted? Models constructed from key physiognomic, physiological or life-history attributes of dominants within a community could form the basis of an autecological approach. Using a synecological approach, at least four distinct components can be recognized (elasticity, amplitude, hysteresis, malleability) which reflect different aspects of the recovery process. These could be measured in the field or derived from modeling, using such community-level attributes as components of diversity, foliar cover, and similarities in composition. (2) What indicators of effects of air pollution on ecosystem nutrient cycling are most reliable? Observing changes in the mineral composition of fresh litterfall during peak litterfall periods may be preferable to measuring foliar nutrient concentrations in relatively small samples of forest species. (3) What is the role of cultural values in air pollution research? What are the social responsibilities of scientists, and how can they be discharged? Examples were given of the role of cultural values and perceptions in the conduct of air pollution research and interpretation of its results. Scientists may assist decision-makers in interpreting the significance of results of air pollution effects on forests by illustrating the external costs generated in the economy by loss of ecosystem functions, as well as structure, due to air pollution damage. In the open discussion that followed, participants discussed the use of air pollution simulation models in making decisions about land use. Modelers indicated that reparameterization of existing vegetation models to local conditions could provide an efficient means of applying existing models to local siting decisions. Field biologists and managers expressed some reservations about the level of precision to be achieved from such a procedure. Some attributes of the forest ecosystem which are most indicative of pollution stress, and hence most usefully incorporated in such models, were detailed, including physiognomic attributes, visible foliar injury symptoms, wood growth rates and lichen composition. At least nine areas in which research is needed on the effects of air pollutants on forests were suggested.

[1]Presented at the Symposium on Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, June 22-27, 1980, Riverside, California, U.S.A.

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OPENING REMARKS

The purpose of this final discussion session is to identify ecosystem-level concepts pertinent to the study of air pollutant effects of forests, and to provide an opportunity for discussion between participants at the Symposium

regarding key questions arising from the Symposium proceedings. To assist in this effort, Symposium session chairmen (Patrick Coyne, Joe McBride, Samuel McLaughlin, Jr., Joseph Shinn, William H. Smith, and David Tingey) will serve as a panel to field discussion questions from the audience. I have been asked to open the session with some "provocative" questions regarding ecosystem-level studies of air pollution effects, arising from the Symposium presentations and field trips of the last four days. I cannot guarantee that anything more than my garish red tie will be provocative, but I would like to pose three questions for your consideration.

HOW CAN RESILIENCE OF ECOSYSTEMS TO AIR POLLUTION DAMAGE BE PREDICTED?

The term "resilience" has been used to refer to the degree, manner and pace of restoration of initial structure and function in an ecosystem after disturbance (Westman, 1978). Most of the papers in this Symposium have discussed not resilience, but what has been termed ecosystem "inertia" (Orians, 1975; Westman, 1978). "Inertia" is the ability of an ecosystem to resist displacement in structure or function when subjected to a disturbing force. In the case of air pollution, inertia can be measured by determining the minimum concentration of a pollutant at which impact to an ecosystem occurs. We have considerable information on the levels of chronic or acute air pollution that will initiate injury to individual species, and a less ample body of evidence regarding the levels of pollutants necessary to initiate community-level changes.

Ecosystem models, once effectively validated, can potentially serve as tools for the prediction of resilience. Since it is impractical to model all features of an ecosystem, however, modelers need to know which attributes of a species make the organism most vulnerable to pollution injury. Thus, to be of maximum assistance to modelers, experimentalists need to determine which physiognomic and/or physiological attributes of a species (or species association) are most useful indicators of the inertia and resilience of species. Noble and Slatyer (1976) and Grime (1979) have made progress recently in identifying attributes of species which may be useful in predicting their ability to recolonize burned or cleared sites.

We might be able to speed the building of efficient models of air pollution effects on ecosystems by examining species for those attributes which are most vulnerable to pollution damage, or which enhance recovery following damage. During this symposium, we heard that lichens and mosses tend to be more vulnerable to air pollutants because of their lack of waxy cuticles. Beyond this, it would be useful to know more about the relative effects of such leaf attributes as mesophylly, sclerophylly and succulence in providing resistance to absorption of pollutants. What is the predictive value of phenological attributes, such as evergreenness vs. deciduousness, or life-cycle attributes such as annual vs. perennial reproductive cycles? What are the effects of crown-sprouting ability, or lack thereof, on ecosystem recovery following air pollution damage?

These questions form part of what might be called the "autecological approach" to ecosystem resilience, since they focus on species attributes which, when incorporated in an ecosystem model, can be used to synthesize key properties of ecosystems.

It is possible, however, that progress may be made more quickly by attempting generalizations of ecosystem resilience by studying community-level processes of recovery in particular biomes. In order to organize a study of community-level response to disturbance it is useful to recognize at least four distinct components of resilience (Westman, 1978):

Elasticity

The rapidity of restoration of a stable state following disturbance. To use the analogy of a metal coil, elasticity of the coil is the time required to spring back to initial size after stretching a certain distance.

Amplitude

The zone from which the ecosystem will return to a stable state. By analogy, amplitude is the distance beyond which a coil cannot be stretched without being permanently deformed.

Hysteresis

The degree to which the path of restoration (succession) is an exact reversal of the path of degradation (retrogression). By analogy, hysteresis is the degree to which the region temporarily occupied by a coil in springing back differs from the region through which the coil moved when initially stretched.

Malleability

The degree to which the stable state established after disturbance differs from the original steady state. Similarly, malleability is the degree to which a stretched coil remains stretched after the deforming force is removed.

These components of resilience are subject to measurement (Westman, 1978). In the case of the study of oxidant effects on pines in the San Bernardino Mountains, inertia was determined by observing the levels of oxidants at which damage to pines first appeared. Amplitude might be established by identifying the sample plots, among the several used, at which pines are no longer replacing themselves (if these are taken to be climax species for the region), and determining the lowest mean and

peak concentrations of oxidants at which this threshhold effect is observed. Elasticity could be measured as the time necessary for recovery of such a site once pollutant stress is removed. Malleability could be measured, using a percentage similarity index, by comparing the community composition of the new steady state which was established following pollution stress to the pre-stress composition. In examining hysteresis, one would ask whether the first species to disappear from the ecosystem were the last to return, using, for example, a rank correlation coefficient.

It is obvious that in many situations recovery cannot be observed because the chronic stress continues (as is the case in the San Bernardino Mountains). Further, the post-stress recovery period may be on the order of centuries, in which case ecosystem models using autecological approaches must be relied upon for quicker predictions. Nevertheless, there are situations in which a polluting source has been removed or reduced, and recovery can be observed. In these situations, compilation of the components of resilience for a particular plant formation may aid us in generalizing about the impact of new pollution sources on as yet unimpacted areas of vegetation of similar type.

Thus in considering the prediction of ecosystem resilience, we may be wise to focus both on sensitive attributes of individual species or species associations, and of community-level changes in species richness, composition, foliar cover, etc. which can form the bases for observing community-level components of resilience.

WHAT INDICATORS OF EFFECTS OF AIR POLLUTION ON ECOSYSTEM NUTRIENT CYCLING ARE MOST RELIABLE?

The nutrient budget of an entire ecosystem represents one ecosystem level attribute that can reveal much about growth-potential and functioning at the supraorganismal level. Determining the nutrient budget for even a small portion of the landscape, however, is a very costly and time-consuming process. Hence some speakers (Bruce Wiersma and K. W. Brown, Allen Legge) described attempts to determine effects of air pollutants on nutrient cycling by measurement of concentrations of mineral elements in foliage, as possible bioindicators of pollution-induced ecosystem-level damage. Paul Zinke described some of the many ecosystem compartments which must be considered in conceptualizing ecosystem nutrient cycling.

I would like to issue a caution against the use of foliar nutrient concentrations, in the absence of considerable context, for the study of pollution stress. Soil scientists have long recognized that foliar nutrient concentrations are dependent on soil nutrient concentrations, and have used the foliage analyses as indicators of "available" concentrations of the elements in the soil in a number of instances. Thus it becomes very important for the air pollution researcher to characterize soil heterogeneities in his or her study. Secondly, ecologists know that foliar nutrient concentrations vary temporally as the leaf passes from early growth stages to senescence and leaf fall. The changes are due to the change in tissue and cellular component ratios with age, to the changing ratio of photosynthate to mineral elements, and to withdrawal of more mobile nutrients into stems before leaf fall. Thus the harvest of leaves at different times of year makes nutrient analyses of these leaves inappropriate for use as samples from a single population. Furthermore, species differ in their abilities to assimilate, retain or accumulate to luxury levels, particular mineral elements. The ability of some species to accumulate certain heavy metals, for example, is the basis for biogeochemical prospecting. Luxury accumulation of potassium by many species is well known. Calcium, being immobile, tends to increase in concentration in leaves with age, but the initial ability to assimilate calcium differs from species to species. Thus the analysis of foliar nutrient concentrations without regard to species or ecotype is to be avoided.

The multiple axes of variation presented by differences in species, mineral properties, time of year and soil concentrations implies that a much more massive sampling program must be undertaken to observe meaningful trends from foliar analyses than has characterized some of the air pollution studies reported.

Short of a full nutrient budget analysis, changes in the mineral composition of fresh litterfall during peak litterfall periods may provide a more suitable indicator of nutrient changes due to pollution stress, as this component is standardized in time, and weighted to the foliar biomass composition of the forest. Even so, large sample sizes are needed, and much caution in extrapolation of results will still be necessary.

WHAT IS THE ROLE OF CULTURAL VALUES IN AIR POLLUTION RESEARCH?

WHAT ARE THE SOCIAL RESPONSIBILITIES OF SCIENTISTS, AND HOW CAN THEY BE DISCHARGED?

As natural scientists, we tend to relegate the social context of our research to other segments of society. We do so at risk, however, because there are both social issues upon which we are most qualified to comment, and sociopolitical forces which affect the choice and conduct of our research problems. In the course of the present Symposium, I was amused to note the variation in perception of the air quality in Riverside during the period, by various participants. Some thought the smog light, others oppressively heavy. The smog concentration was a constant; cultural values were at work in influencing perceptions. As a second example,

some speakers emphasized the role of acid rain as a fertilizer, while others emphasized its toxic properties. Of course, whether any pollutant will exercise its toxic properties will depend upon rate and duration of application, and concentration, as well as upon the physiological state of the receptor organism and its ecosystem. In the case of characterizing the properties of acid rain, however, the attributes chosen for emphasis were chosen for reasons having to do with the cultural attitudes and values of the speakers, and not because of disagreement over empirical observations. As a third example, we heard from one Forest Service representative during the field trip that the damaged portions of the San Bernardino National Forest were not experiencing difficulty in reproduction. But, the E.P.A. sponsored, University of California-Forest Service research team provided evidence to the contrary. Were these two parties disagreeing over empirical observations, or was their difference one of cultural values and perceptions applied in evaluating the significance of the same body of data? As a fourth example, recall that about 50% of the adult American population smokes, thereby bringing into their lungs several times the ambient levels of particulates and toxic gases present in polluted urban air. Will these people perceive the human health hazards of outdoor air in the same way as nonsmokers? Will they assign the same weights to their importance?

At the very least, scientists have a responsibility to differentiate clearly between empirical observations and normative (value) judgments. But does our responsibility to decision-makers and the public stop there? Much has been said regarding the appropriateness of scientists in offering value judgments to society, and I will not enter the debate here. I would, however, like to suggest a way in which scientists can help to clarify in socially-meaningful terms the social costs of air pollution damage.

I believe decision-makers would profit from a fuller understanding of the effects of air pollution not only on the marketable aspects of ecosystem structure (standing timber, crop yield, tourist revenue), but also on those aspects of ecosystem functioning which create hidden costs in the market place. To take an example from the San Bernardino National Forest oxidant study which I have previously discussed (Westman, 1977), consider the dollar costs to society of the loss of the soil binding function from air pollution damage to pines in this forest. As of 1972, 57% of the trees over a 4000 hectare area will be replaced by a retrogressive vegetation of forbs and grasses, and that erosion losses from the latter will increase in the proportion observed when chaparral was converted to grassland by the U.S. Forest Service at San Dimas in the neighboring San Gabriel Mountains, it is possible to estimate erosion losses from the stressed forest. At current rates of cleanup of sediment from streets, sewers and debris basins, the cost of damage from loss of the soil binding function of the San Bernardino Mountain pines is $27 million per year. These costs are being absorbed currently by the general public not only as direct tax collection to local governments cleaning up the sediment, as only a portion of the sediment is being recovered in this way. The costs are being absorbed also in terms of losses to fisheries in coastal waters where spawning areas are smothered by sediments, by public works allocations for new dams, by flood damage following storms in silted flood channels. Rarely if ever are these costs attributed to smog and considered in the cost-benefit analysis of proposals to install emission control devices. Further, soil binding is only one of the functions destroyed through death of the pines. Loss of the functions of nutrient capture and retention, pollution absorption, climatic regulation and energy fixation all have their social costs, capable of at least partial enumeration and evaluation (Westman, 1978).

Complex as this process of social cost identification is, I suggest that it is a topic in which scientists can play a larger role than we have to date, and a topic to which, it may be argued, we have a responsibility to contribute.

SUMMARY OF AUDIENCE PANEL DISCUSSION

Use of air pollution simulation models in decision-making

Discussion ensued on the current applicability of computer models to such immediate questions as how to site power plants to minimize damage to vegetation. Those with experience in building models expressed considerable confidence that these could be used, upon reparameterization, to help resolve such questions in a number of parts of the country. Experimental biologists and land managers expressed concern that the models were still too broadly conceived to provide accurate estimates of differences between sites in a single vegetation type. A number of the specific issues that were broached as part of this discussion are as follows:

Transferability of models between vegetation types

What level of resolution of a model is needed in order to provide accurate predictions of pollution effects on vegetation, of use to land managers? Are single general models for each biome sufficient, or do we need a model for each of 400 or 500 American vegetation types? How should a model be constructed to maximize its transferability between regions? Several suggested responses were offered:

1. The work of ecologists, air pollution research scientists and modelers could be

oordinated in a nationwide research laboratory onsortium to construct working models of air ollution effects on vegetation for the major egional plant formations. Land managers conerned with particular siting or forestry quesions in a region of the country could submit request to the consortium for adaptation of a egional model to his or her particular probem. One advantage of this approach is that iologists and modelers who are most familiar ith the assumptions in the model would be vailable to operate the model. Repetitious esearch efforts could be avoided, and experence accumulated from various regional efforts.

. Models which incorporate the mechanistic asis for air pollution effects on vegetation ay be most easily adapted to new vegetation ypes with accuracy. "Mechanistic" bases may onsist of physiological models of the effects f pollutants, temperature and moisture on utrient assimilation and photosynthesis, or hey may consist of ecosystem-level models in hich sensitive attributes of the ecosystem litterfall, evergreenness vs. deciduousness, pecies longevity) are modeled.

. The National Power Plant Team of the United tates Fish and Wildlife Service has available power plant siting model which, although conidering various constraints, does not incororate a model of air pollution effects on vegeation in detail. They have recently obtained, owever, a copy of Kercher's (Lawrence Livermore Laboratory) forest growth model, and plan o make this available for public use, and peraps ultimately link it to their existing siting odel.

. A forest growth model for a particular veetation type appears to require 1 - 2 personears of effort to construct from scratch. Rearameterization of an existing model is rearded as a less costly and time-consuming way o provide a model for a new vegetation type. n important limiting factor to this effort s the paucity of field and laboratory fumiation data on effects of air pollutants, alone nd in combination, on species, especially over xtended periods. In the absence of such field ata, sensitivity analysis of the computer odel may be used to establish the likely comonents of the ecosystem which will be most dversely affected by a particular stress, and o produce qualitative scenarios of worst case vents.

. Existing models for many vegetation types o not incorporate long-term cyclical events uch as fires, seed cycles, etc. However, moels such as those of Kercher do incorporate hese effects. The forest growth model available through Oak Ridge National Laboratory is onsidered capable of application to all eastern . S. forest types except Southern pine forests.

Ecosystem-level indicators of pollution stress

What attributes of species or of ecosystems can be used by field ecologists and modelers as sensitive indicators of likely pollution-induced changes?

1. Physiognomic attributes (leaf cuticle thickness and chemistry), phenologic attributes (age to reproduction, duration of foliage), and life hisrory attributes (annual vs. perennial nature, longevity of generations) are seen as community-level indicators. Litterfall may be a useful indicator of nutrient budget processes.

2. Growth rings (dendrochronology) may be used as a long-term record of forest growth responses. In Pennsylvania, for example, tree ring analysis in forest in the vicinity of power plants has been conducted.

3. Visible injury symptoms, such as the foliar injury index used by Paul Miller and co-workers, may be useful. The Tennessee Valley Authority has recorded visual injury symptoms on trees surrounding a number of its power plants.

4. The use of particularly sensitive species, such as lichens, was illustrated earlier in the Symposium.

Use of models in setting air pollution standards

Can air pollution models be used by agencies concerned with establishing minimum concentrations of ambient exposure that will cause damage to vegetation?

1. To the extent that standards incorporate social values as well as scientific criteria, a computer model of the type being discussed cannot be used to set a standard.

2. On the other hand, computer models have been used to determine levels of forest growth reduction from particular levels of pollutants. This information alone, or converted to economic loss figures, can be useful as information for criteria documents used in standard setting.

3. Models have been used to calculate radiation dose to people in the vicinity of nuclear power plants. The Indian Point power plant was modified to reduce damage of effluent to fish life, based on information obtained through a computer model.

4. Models of forest growth have illustrated that even a 5-10% decrement in tree growth due to air pollution can have severe long-term effects on forest growth and composition. This is a prediction that would have been difficult to make with precision in the absence of a computer model.

A Research Agenda

During the course of the synthesis session several suggestions were made regarding areas in which important information is particularly lacking. These research topics are listed below.

Patterns of Recovery in Stressed Vegetation--While many ecosystem studies have documented the 'inertia' of the systems, fewer have observed the recovery process. The emission source at Trail, British Columbia, is an example of a point source whose emissions decreased dramatically in the late 1930's. Studies of subsequent recovery of damaged vegetation could tell us much about resilience of that forest ecosystem.

Precipitation Chemistry--Much needs to be known about the chemical transformations in rain and snow as they pass over the surfaces of vegetation and soil, and how these in turn affect the flux of nutrients in the ecosystem.

Mechanistic Models For Particulate (including heavy metal) Pollutants--Models for the injury to plants from toxic gases are more advanced than those for particulates. How do particulates enter plants and at what rates? How are their effects registered? How can they be modeled?

Synergisms--Much is unknown about the interactive effects of several air pollutants on individual species and on ecosystems. Fumigation studies should incorporate pollutant combinations as well as test the effects of single pollutants.

Long-term Effects of Pollutant Exposure--There is a need for laboratory studies of long-term exposures (greater than one month) of air pollutants to species. In the field, exposures to forest species occur over many years. It is difficult to understand long-term effects on reproduction and growth in the absence of chronic exposure studies.

Monitoring Data For Ambient Pollutant Concentrations--More of these data are needed for all parts of the United States if use of computer models with realistic ambient air concentrations is to be achieved. The same data are needed for interpretation of field observations.

Interaction of Air Pollution Stresses With Management Practices--How does the effect of an air pollutant on a forest differ under different thinning regimes? This question may be examined in the next phase of research in the San Bernardino Mountain pine forests.

Carbon Dioxide Enrichment in the Atmosphere--Rising ambient CO_2 levels are affecting forest growth. How do these effects interact with ambient air pollution levels? How will the affect of CO_2 on global climate further affect pollution response of forests?

Funding of Research on Forest Growth Models Specifically Built to Incorporate Air Pollution Effects--Most existing models simulate forest growth in the absence of pollution effects, and were funded by agencies other than those concerned with air pollution.

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Integration: a Role for Adaptive Environmental Assessment and Management[1]

Nicholas C. Sonntag, Robert R. Everitt, Michael J. Staley[2]

Abstract: Adaptive Environmental Assessment and Management (AEAM) is a proven methodology for integration and analysis of environmental research and management. Simulation modelling workshops are an essential part of the process. They act as a catalyst to focus analysis, stimulate discussion and foster communication amongst managers, planners and scientific disciplinarians.

Some of the philosophy and methodology are described along with a case study example on the Alberta Oil Sands Environmental Research Program (AOSERP). The emphasis is on how AEAM can help foster integration and communication of scientific information.

Over the last decade we have seen phenomenal owth of environmental science. It has spawned proliferation of public and private institutions dicated to environmental research and protection. vironmental research and management have become ghly skilled, influential, and more often than t, respected professions. Governments have eated such well meaning provisions as the tional Environmental Policy Act (NEPA), the Clean r Act and the Water Quality Act in the United ates, and the Environmental Assessment and view Process (EARP) in Canada.

These gallant efforts to research and protect e environment have over the years generated luminous amounts of information; information tended ultimately to provide knowledge to help nkind better manage the world's environment and sources.

The challenge today is to analyze and make nse of the vast amount of data and knowledge. fortunately most research has been disciplinary based, and inspite of a desire for interdisciplinary coordination most large research programs have failed to integrate their results. One reason for this is the lack of a proper forum for communication amongst scientific specialists; another is the absence of a systematic framework for synthesizing results. While some programs have been successful at pulling the individual studies together few have been able to make the results relevant to environmental management. Many argue that this can be remedied by raising the quality of environmental research. Unfortunately there is a dichotomy between environmental research and environmental management. Research science cannot effectively guide managers because scientists do not readily comprehend management concerns; management cannot adequately direct research science since managers often do not have scientific knowledge or the breadth of understanding such knowledge provides. This inability of scientists and managers to interact effectively has been a major stumbling block in developing progressive policies and attitudes towards the environment both in the public and private sector.

Adaptive Environmental Assessment and Management (AEAM), well documented in Holling (1978), has evolved over the last ten years into a proven methodology for integrating environmental research while linking research and management. AEAM uses computer simulation modelling in a unique and novel way. Within a structured modelling workshop, the

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task of constructing a simulation model acts as a catalyst to focus analysis, stimulate discussion and foster communication amongst managers, planners, and scientific disciplinarians.

BIASES OF AEAM

Ecologist's understanding of ecosystem structure and behaviour have come from four basic properties which determine how ecological systems respond to change (Holling, 1978).

1. The parts of an ecological system are connected to each other in a selective way (this has implications for what should be measured).

2. Events are not uniform over space. (This has implications for how intense impacts will be and where they will occur.)

3. Sharp shifts in behaviour are natural for many ecosystems. (Traditional methods of monitoring or assessment can misinterpret these and make them seem unexpected or perverse.)

4. Variability, not constancy, is a feature of ecological systems that contributes to their persistence and to their self monitoring and self correcting capabilities.

Underlying each of these properties is the fact that environmental systems are characterized by overwhelming uncertainty. Man's understanding of the underlying biological, social and physical processes and interactions is minimal, and will remain so for the forseeable future. The complex and pervasive nature of environmental and social issues guarantees our ignorance will always exceed our knowledge.

The many sources of error in environmental systems ensure that no matter how broad or deep an analysis inevitably something outside will influence the results and violate the predictions. The conclusion is that environmental and social systems are fundamentally unpredictable. If you accept this hypothesis then, how can environmental science produce effective research and management.

First and foremost we must never promote research and analysis as the panacea for prediction of the fate of society and its environment. Second, we must recognize that decisions are always made under uncertainty, and ignorance. Realizing this we must capitalize on methods that help focus ideas and information, integrate concepts, and guide decision making. Better decisions will usually be made with a clear picture of both knowledge and ignorance, and a broad appreciation of the consequences of action.

The key tool of AEAM is the computer modelling workshops. These short intense meetings circumvent the natural scientific tendency for reductionism and the eternal cry for more studies. Participants in these workshops are forced to recognize that all components of natural resource systems are not of equal importance and judgment is the tool of management not exhaustive research.

MODELLING WORKSHOPS: THE CORE OF AEAM

A modelling workshop is a 3 to 5 day meeting o a group of scientists, planners, and managers involved in the design and execution of an environmental study. No papers are presented, there is no keynote speaker, there are simply 3 to 5 days (focussed activity on the problems at hand. The development of a computer simulation model of the physical, biological, and social aspects of the problem serves as the focus for the workshop.

Participants in the workshop do not need any knowledge of computers or modelling to contribute to the workshop and to gain from its results. Workshop facilitators translate participant input into quantitative relationships that can be programmed into the simulation model. The facilitators can be viewed as information translators for it is the participants who conceptualize the mode Therefore the model that evolves from a workshop is as much a product of the ideas and concerns of people unfamiliar with modelling as it is a produ of those familiar with simulation techniques.

The obvious objective of a modelling workshop is to build and run a computer simulation model o the bio-physical system of interest. However, th resultant model is not an end in itself. Usually its predictions are not very precise and it often lacks obvious features of the actual system. Rather, the model is a focus for communication promoting objectivity and honesty. Building the model forces the participants to formalize their understanding of the system components and interactions. This facilitates easier evaluation of t importance of interactions to the system and the workshop objectives. Often favoured factors turn out to be irrelevant for predictions, therefore requiring less future effort both in model develo- ment and data-gathering programs.

As with many modelling studies, a workshop gen erated model confers the ability to test hypothes, research plans and different management policies without risk. However, that is where the similarcy usually ends. Since a workshop model is designed and built by all the participants its structure and resultant dynamics are "transparent" to the user. The model is comprehensible. This inspire trust and increases insight thereby promoting generalization of the model projections. It alsc facilitates easier evaluation of those factors le out of the model.

The modelling workshop style prevents the buil- ing of a sophisticated state of the art simulatio model. The workshop model is invariably simple i structure and inefficient in operation. Further striving to simplify the problem the need for sophisticated tools such as complex implicit (or explicit) finite difference methods for approxima- ing differential equations are usually avoided.

though the precision of the model's predictions y suffer simplification does not deter from the jectives of participant involvement, communica- on and understanding. People are the key mponents in the modelling workshop not the model. is does not have to be the case after the work- op. Often the model structure established serves an excellent guide for future modelling efforts en more consideration can be given to the "art" simulation modelling.

By definition any simulation model is "wrong" nce it must be a simplification of reality. wever, complex models do not necessarily make tter predictions. As the number of variables creases, so does the number of assumptions about w they are related and the chances of making a itically wrong assumption rises rapidly. There- re parsimony is the underlying workshop modelling eme. Interactions and relations should make sense en interpreted in terms of physics and biology. gical consistency and clarity are stressed in e building of the workshop model and go far in intaining its "transparency" to the participants.

The incorporation of modelling workshops in the AM process is designed to be iterative. By cating them between sequential field programs e researchers and managers have the opportunity adapt research plans and management policies light of new insights emerging from the modell- g workshop exercise. The AEAM process, and ecifically modelling workshops, can be success- lly implemented at any point in a study, right to the end. The integration and coordination pects of modelling workshops provide a useful hicle for communication among those responsible r preparing environmental overviews and assess- nts. This ensures they are pertinent, credible, d address the questions being asked. Further e resultant model (after some refinement) ovides a very effective device for summarizing d presenting the results of a study to policy kers, administrators and/or funding agencies. workshop held in 1979 on the Alberta Oil Sands, a good example of such an application.

ASSESSMENT OF THE ENVIRONMENTAL EFFECTS OF ALBERTA OIL SANDS DEVELOPMENT

Setting

"The development of the Athabasca Deposit, one several oil sands deposits in Alberta, has been e subject of intense interest for several de- des. The Athabasca Deposit contains more than 0x10^9 barrels of bitumen reserves, and consti- tes about 88 percent of known oil sands in berta. Consequently its potential to augment e oil supply of Canada has been a driving force present development, and will continue to gen- ate pressure for further development...

...The Government of Alberta has an established licy of environmental legislation which allows r the orderly development of resources with a minimum of environmental damage. This policy resulted in particular attention being paid by regulatory agencies to the need for development of an environmental research program for the Athabasca Oil Sands region. Consequently, late in 1973, officials of Alberta Environment (Research Secretariat) and Environment Canada (Environmental Management Service) separately produced internal reports recommending a comprehensive environmental research program. Projections in each of the reports favoured an environmental research program lasting 10 years, with total costs estimated in the range of \$30 million to \$40 million." (Smith 1979).

The Alberta Oil Sands Environmental Research Program (AOSERP) began in April, 1975. Early investigations were used primarily to establish large data bases. The data bases were intended to facilitate the construction of models to aid in predicting physical, chemical, biological, and social impacts of Oil Sands development.

In the fall of 1979, AOSERP sponsored an AEAM modelling workshop. By this time the program had been organized into four systems: Air, Land, Water and Human. The objectives of the workshop were: (1) to construct a simulation model that would provide a mechanism of integration of the plethora of AOSERP data and information; (2) to delineate the interrelationship between the systems (Air, Land, Water, Human) that are basic to a general understanding; (3) to identify and evaluate data gaps and uncertainties about system function; and (4) to evaluate and recommend approaches to environmental management in the oil sands areas, including mechanisms for technology transfer from AOSERP to Alberta Environment regulatory branches (Staley and others 1979). The participants in the workshop included the director of AOSERP, the heads of the Air, Water, Land and Human systems, the chairman of the Research Secretariat of Alberta Environment, as well as numerous government scientists and planners, and private consultants.

Simulation Model

During the bounding exercise, the workshop decided to consider the entire AOSERP study area which comprises approximately 2.86x10^4 square kilometers of northeastern Alberta, Canada with the spatial resolution based on the area's 13 water drainage units. To assess impacts over a meaningful period, a thirty year time horizon with a yearly time step was used. Important system phenomena operating on a shorter time scale were represented implicitly within the one year step. The simulation model was divided into four interrelated submodels: human, physical transport, aquatic biology, and terrestrial.

The human submodel consisted of three components:

1. An industrial component that generated a number of different development scenarios.

2. A population component that estimated the population based on background growth and development related growth scenarios.

3. A land component that calculated the land requirements for urban, industrial and transportation needs.

The transport submodel was concerned with the physical transport of water, air, and associated pollutants throughout the AOSERP area. The water component was a simple hydrological model of the flow within the 13 water drainage units. Relevant water pollutants were selected as water quality indicators and their concentrations were calculated for each water drainage unit.

The aquatic biology submodel was concerned with the impacts of commercial and recreational fishermen, instream flows, and instream pollutants on four common fish species.

The terrestrial submodel was responsible for representing the vegetation and wildlife dynamics. The model concentrated on the economically important species moose and beaver and their habitat.

RESULTS

A detailed description of the simulation model and its results are found in Staley et al. (1979). However, the results of applying the AEAM process are far more important than the output of the model. Each submodel made explicit a number of data and information gaps. At the conclusion of the workshop it was apparent that many of the data gaps revealed by the simulation modelling exercise could be filled by appropriate reorganization of the AOSERP data base. However, it also became clear that a further conceptual understanding of the environmental system under study was needed before a detailed analysis of the effects of oil sands development could be made. This has important implications for future research since the data baseline has been established. Further research should concentrate on understanding the dynamics of the system. In other words the focus needs to be on those things that cause variation and change in the system, and not on the current state of the system.

The simulation model itself provided a vehicle for integration of five years of environmental research. The process of building the model in the workshop revealed a number of important relationships between the (Air, Water, Land, Human) systems that are basic to an overall understanding.

The application of the AEAM process to AOSERP is not complete. The next phase which should be completed in the fall of 1980 will concentrate on developing the model as a tool to aid environmental management in the oil sands area. The many conceptual weaknesses and bad data in the simulation model will be remedied through a series of technical meetings to be held with the staff of each of the Human, Land, Water and Air systems. The results of these meetings will guide model refinement. The final model will be put together in an integration workshop where the participants of the original workshop and the technical meeting will interactively game with the model. Once the model goes through this "trial by fire" before its creators the model will be used to evaluate a number of environmental management strategies. This will be done in an one day policy workshop focussed on the evaluation of the model's projections. It is the results of this latter stage that will measure the degree of success of this application of AEAM.

CONCLUSIONS

The AEAM process represents the combined learning of a number of international scientists and practitioners and is in a state of "dynamic equilibrium", continually adapting in light of new experience. But the term "adaptive" stresses a more important lesson, the need for research and management to be open to change and to be adapt in both style and content when new information becomes available. While AEAM itself is in a continual state of change, its two underlying themes, expect the unexpected, and learn to plan and plan to learn, never change.

Utilizing the modelling workshop provides many benefits to the success of the AEAM exercise. It forces participants to focus on the relevant issues, promotes interdisciplinary communication, identifies information needs, provides a framework for evaluation of existing information and management actions, and is a guide for environmental policy design.

AEAM through its use of simulation in the workshop setting provides a mechanism for integrating information and facilitating the analysis of impacts rather than massaging baseline data. It is through thoughtful synthesis, analysis and effective communication of environmental information that environmental managers and researchers will make effective use of their resources: time, money and expertise.

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›oster Summaries

Effects of Oxidant Air Pollutants on Pine Litter-fall and the Forest Floor[1]

Rodney J. Arkley and Rudolph Glauser[2]

Oxidant injury to western yellow pines (Pinus ›nderosa and P. jeffreyi) in the San Bernardino ›untains results in needle injury followed by ıcreased fascicle mortality and abscission, ›creased needle length, branch mortality and ınally tree mortality. The degree of injury has ›en estimated each year for 6 years by a scoring ›stem based on observation of all of these ıctors with binoculars and combining them into a ıngle oxidant injury score (OIS). Foliage ›nsity is directly proportional to OIS as ›pected. The number of annual needle-whorls ›tained (W) is related to the score by W = 0.171 OIS with r = .75** and the grams of needles per ›ig by F = 2.71 x OIS with r = .62*. Note that ›S decreases with increasing injury and a score › 0 indicates a dead tree. Scores greater than › indicate no obvious injury.

EFFECT ON NEEDLE-FALL

The oven-dry weight of needles collected on 209 m^2 screens placed under pines of varying ›S is shown in Figure 1. The average annual ›edle fall increases from 131 gm/m^2 under ›althy trees to 357 gm/m^2 with OIS of 9 to 14, ›d decreases as the tree nears death.

The weight per needle fascicle in the litter-›ll decreases progressively with increasing ›jury as shown also in Figure 1. (Sig. < .001).

The increased litter-fall (170 percent) can › expected to increase the thickness of loose ›y litter on the forest floor with consequent ›creased fire hazard and decreased seedling ›rmination.

Plant Nutrient Content

Litter-fall samples were analyzed to determine ›e effect of oxidant injury on the plant nutrient › the litter. The results are shown in Figure ›. The scatter of points (not shown) represented › the regression lines is wide, but 187 samples ›re analyzed and the trends indicated are ›learly real, since they are highly significant › = < .001). Magnesium was also analyzed but showed no trend whatsoever.

The response of these elements is perhaps due to declining cell wall thickness with its calcium pectate and an inverse dilution effect on N, P, and K.

The data for the regression lines shown in Figure 2 are as follows:

N(pct) = .598 - .00255 OIS, r = -.264, n = 187
P(pct) = .0707 - .00034 OIS, r = -.28, n = 185
K(pct) = .346 - .00331 OIS, r = -.37, n = 187
Ca(pct) = .303 + .00431 OIS, r = .58, n = 147

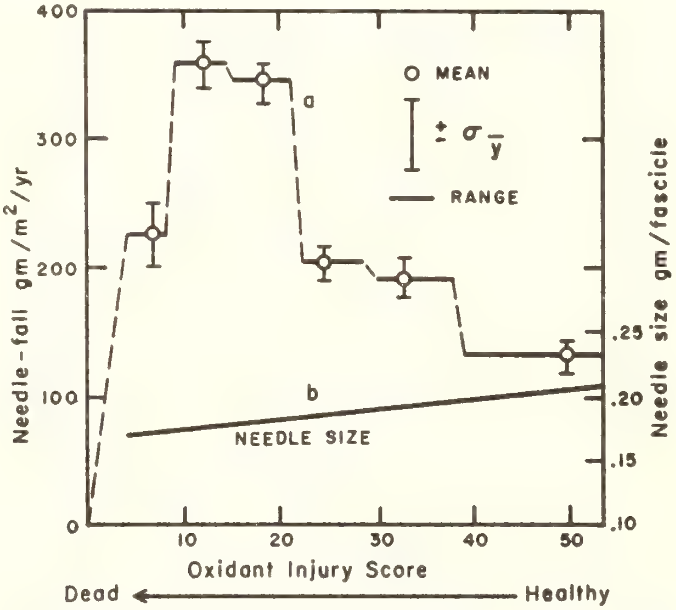

Fig. 1. Effect of oxidant injury on pine needle fall and needle size.

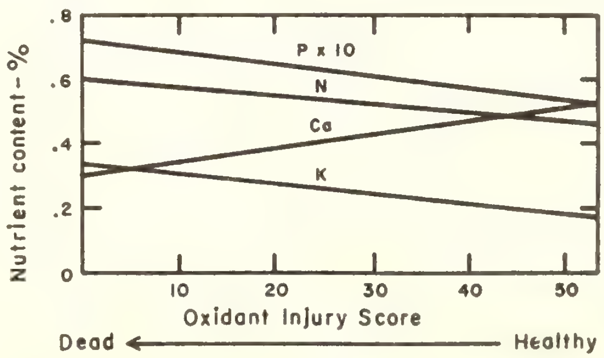

Fig. 2. Needle-fall content of plant nutrients.

[1]Present at the Symposium on Effects of Air ›llutants on Mediterranean and Temperate Forest ›cosystems, June 22-27, 1980, Riverside, ›alifornia, U.S.A.

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Regional Air Pollution Impacts on Forest Growth[1]

Thomas V. Armentano, Orie L. Loucks, and Wayne T. Williams[2]

Recent studies underway in the Ohio River Basin Energy Study (Loucks 1980) have shown that chronic air pollution levels may be reducing regional growth over much of eastern North America. During June through August, 1977, monitoring stations representative of forest areas recorded hourly maxima $\geq$ 0.10 ppm on 14 to 27 percent of the days, and maxima $\geq$ 0.05 ppm on 70 to 93 percent of the days.

A survey of eastern white pine (*Pinus strobus* L.) stands in rural and urban locations throughout central and southern Indiana showed widespread ozone damage symptoms: chlorotic mottling, chlorotic dwarfing and premature needle senescence, on a scale from moderate to severe. Sycamore (*Plantanus occidentalis* L.), silver maple (*Acer saccharinum* L.), yellow poplar (*Lireodendron tulipifera* L.), and the black oak group (*Quercus* spp.) also are somewhat sensitive. The 37.3 x 10^6 acres of forests in the Ohio Basin yield about 40 $ft^3/acre^{-1}$ of wood annually, but an estimated 25 percent of the forest consists of O_3-sensitive species, indicating a yield reduction from oxidant effects (and interactions with other gases and pathogens), ranging from 3 to 6 percent annually (Table 1).

Table 1--Total loss in wood production in Ohio River Basin forests estimated to result from direct and indirect air pollutant effects upon forest growth and mortality rates. Total normal wood yield for the region in 1970 was 1.5 x 10^9 ft^3. Data expressed in millions of cubic feet.

Year	Wood Production Loss (Pct.)	Wood Production Loss ($10^6 ft^3$)	Annual Mortality Loss (Pct.)	Annual Mortality Loss ($10^6 ft^3$)	Total Loss (Pct.)
1970			2.7	40.3	
1977	3-6	45-90	5.4	80.6	8.3-11.3
1985	5-11	75-166	10.8	162.8	15.8-21.9
2000	5-11	75-166	10.8	162.8	15.8-21.9

Independent studies indicate O_3 levels will increase in the Ohio River Basin over the next 20 years, depending on increases in utility NO_x emissions. A conservative energy development scenario suggests that O_3 levels will continue upward at least through 1985. At the current rate of O_3 increase, 0.02 ppm per decade, wood losses could reach 166 x 10^6 ft^3, twice the current estimated losses (Table 1).

A pattern of increasing tree mortality in the relatively young eastern forests (30 percent mortality increase in the Northeast, and 10 percent in the South from 1962 to 1970) has been reported during a period of significant air pollution increases in the Northeast (U.S. Forest Service 1978). This mortality may be attributable, at least in part, to degradation of air quality. This hypothesis is supported by nearly constant mortality in western forests where air pollution is generally low, despite overmaturity in these forests. If mortality losses in the Ohio Basin were intermediate between those of the Northeast and South from 1962 to 1970, the loss of wood would be 4.08 $ft^3/acre/yr^{-1}$. Proportionately greater losses are indicated for 1985 and 2000 (Table 1).

Other studies underway indicate these forest losses could be significant for the global CO_2 balance (Armentano and Ralston 1980). Because of a favorable stand age distribution brought on by past harvest patterns, temperate zone forests now store around 10^9 tons of carbon annually in long-lived tree components, 20 percent as much as the carbon released from fossil-fuel combustion. This storage could continue for the next two decades, but increased harvest, forest maturation, and air pollution effects can reduce carbon sequestering and wood production rates. Thus, only management of forests focused on a balance between wood production and wood accumulation can provide optimum economic and ecological benefits. If present air pollution trends continue, and if relationships to forest growth suggested in this paper are substantiated by further research, the long-term productivity of forests will be threatened in several regions of the United States.

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Canopy Analysis of Pollutant Injured Ponderosa Pine in the San Bernardino National Forest[1,3]

M.C. Axelrod, P.I. Coyne, G.E. Bingham, J.R. Kercher, P.R. Miller, and R.C. Hung[2]

Nine trees were selected from a ponderosa pine Pinus ponderosa Laws.) stand which was estab- ished after a fire in the mid-1950's. These rees were classified into three injury groups, (1) slight, (2) moderate, and (3) severe injury] n accordance with a scoring devised by P.R. iller. During the summers of 1978 and 1979, a etailed inventory was made of the canopy on each ree. The lengths of all main stem internodes ere measured along with the number of primary ranches radiating from each of these internodes. t roughly every other main stem internode, sev- ral of the primary branches received a detailed nventory. The length of the primary branch and ne number of internodes were recorded. This in- entory was carried on through to the secondary, ertiary, and quarternary branch levels. The ompass angle of each of the inventoried primary ranches was also recorded. Whenever needles were ound on an internode, the following information as recorded: (1) needle age, (2) needle condi- ion on a scale of 0-4, (3) the number of fasci- les, (4) the average needle length, (5) the verage needle chord width, and (6) the length of ne internode bearing the needles. Note that hile not all the primary branches at a selected ain stem internode were inventoried, the ones elected did receive a complete inventory.

A preliminary analysis of the 1978 canopy data as been completed, characterizing the distribu- ion of needle surface area for each tree. The otal needle surface area for each inventoried rimary branch was computed separately for each eedle age. In order to determine the distribu- ion of needle surface area for a whole tree, we stimated the needle area at the main stem inter- odes where no data was taken. The curve repre- enting needle area as a function of height is pproximately bell-shaped. We have developed an lgorithm designed to yield estimates of the issing points and a smooth curve. The algorithm s iterative and uses linear interpolation between known points to produce a set of initial estimates. The algorithm first computes the cumulative needle surface area as a function of height, then a linearizing transformation is made. Linear interpolation is carried out on this new curve. The transformation is then inverted and first differences taken, resulting in a reproduction of the original data and a new set of estimates for the missing data. The new estimates are used as initial values each iteration. A weighted average of the needle conditions for each primary branch was also computed. These averages are then combined to yield an index of the condition of the needles on the whole tree.

In table 1A, we see the total leaf area index for each needle age class, with the trees grouped into injury classifications. We can see the leaf area indices decrease across injury classes within age groups. There is a pronounced decrease in the retained leaf area with needle age even in the slightly injured group; the severely injured group has essentially no needle area except in the 1 year age category. Table 1B shows the (weighted) average needle condition for the inventoried trees and presents further evidence that ozone injury is dose accumulative with young needles being less affected by ozone than older needles. Since the current year needles were still growing at the time the initial inventory was taken, they were inventoried separately the following year. This data is still being processed and is not yet available, but is expected to add proportionately to the numbers presented here. The trend in leaf area decline indicates the competitive disadvantage of an injured tree.

Table 1--Needle properties by needle age for nine trees under pollution stress.[1]

Injury Class	1 Year	2 Year	3 Year
	(A) Leaf Area Index		
Slight	9.53	4.13	0.70
Moderate	5.23	0.73	0.00
Severe	3.55	0.03	0.00
	(B) Average Needle Condition[2] of Canopy		
Slight	0.96	1.31	1.28
Moderate	2.18	2.42	NA
Severe	2.63	NA	NA

[1]Does not include data for current year needles. Averages for 3 trees in each injury class.

[2]Needle condition scale: 0 = green; 2 = chlorotic mottle. 4 = uniform yellow with necrosis.

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[3]Work performed under the auspices of the U.S. epartment of Energy by the Lawrence Livermore atl. Laboratory under contract number W-7405- NG-48.

Photosynthesis and Stomatal Behavior in Ponderosa Pine Subjected to Oxidant Stress: Water Stress Response[1,2]

Gail E. Bingham and Patrick I. Coyne[3]

Light response curves for net and/or gross photosynthesis, stomatal conductance, and needle xylem potential of ponderosa pine (Pinus ponderosa Laws.) subjected to water and/or ozone stress were studied in the field and laboratory. In the field, measurements were made on a stand of ponderosa pine in the San Bernardino National Forest, which has experienced long-term oxidant fumigations from the south coast air basin since their establishment following fire in the mid-1950's. These trees were stratified for comparative studies into three groups (slight injury, moderate injury, and severe injury) having similar oxidant symptoms, on the basis of the scoring system of P.R. Miller.

Controlled studies using ten healthy, uniform, Oregon-grown, six-year-old saplings growing in 55 l containers were conducted to elucidate specific field responses. These trees were approximately 2 m tall, and were randomly allocated to positions in two naturally-lighted, mylar-covered, air and humidity conditioned exposure chambers. One chamber was supplied charcoal filtered air and the other with air containing 0.01 ppm ozone for six hours/day during the midday period.

Measurements were made at regular intervals from May through October at the forest site and during the fumigation and water stress cycles in the laboratory. During the laboratory study, net photosynthesis (P_n) and stomatal conductance (C_s) measurements were made at constant humidity and temperature using the LLNL developed minicuvette system, with only the fascicle being measured and a few surrounding needles exposed to light. The rest of the tree was surrounded with heavy black cloth from before dawn until after light response curves had been measured on three fascicles.

The relationship between needle xylem potential (ψ_x) and maximum stomatal conductance (C_{max}) was not single valued, and depended on predawn ψ_x. When predawn ψ_x was in the range from -3 to -5 bars, C_s (and P_n) decreased only slightly during the normal daily decrease in ψ_x due to changes in the diurnal course of irradiance. Minimum ψ_x under these conditions seldom exceeded -14 bars. However, when ψ_x was forced below -15 to -17 bars (by severing the fascicle from the branch) a sharp decrease in C_s occurred, with complete stomatal closure (C_s<0.01 cm/s) in the range of -36 to -40 bars. When predawn ψ_x started in the -5 to -8 bar range, however, a bilevel relationship between C_s and ψ_x was observed, with C_{max} reaching an initial full light value, followed at some later time by a step decrease to a lower value. Conductance and P_n remained at this significantly lower level throughout most of the day, with an accelerated closing trend toward the late afternoon. Late afternoon values were usually only 60 to 70 percent of their light corrected morning opening value.

Care had to be taken when interpreting pre-dawn ψ_x measurements in the field. It was often observed that at a predawn ψ_x of -3 to -7 bars, the stomata would partially open in the predawn hours resulting in C_s values approaching one-tenth of their full light value. Under these conditions, sufficient transpiration occurred to make predawn ψ_x very sensitive to wind speed. Differences between predawn ψ_x on calm and windy mornings as large as 3 bars were observed.

The second factor depended solely on the predawn xylem potential and controlled the maximum stomatal conductance (C_{max}) observed during the diurnal cycle. This relationship could not be adequately examined in the forest due to untimely late season rains during the three years that field studies were conducted, and was investigated using potted trees. As predawn ψ_x decreased below -7 bars in control trees and about -10 bars in fumigated trees, a drastic reduction in C_{max} and P_n was observed. In trees kept in filtered air, C_{max} was decreased from 0.36 to 0.036 cm/s by the decrease of predawn ψ_x from -5 to -15 bars. Since the majority of the tree was kept in the dark during the measurement, the relationship between C_s and ψ_x at ψ_x values greater than can normally be observed in nature (due to root and xylem resistance) were examined. Conductance and P_n of fumigated trees in this region was not significantly higher than that observed at potentials associated with full illumination. Reductions in C_{max} of 2[illegible] 31, and 44 percent were measured for slight, moderate, and severely injured needles. Net photosynthesis for the same needle injury classes was reduced by 38, 54, and 69 percent from the 12.9 $mgCO_2/dm^2$-h rate measured in trees which had not been exposed to ozone.

[1]Presented at the Symposium on Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, June 22-27, 1980, Riverside, California, U.S.A.

[2]Work performed under the auspices of the U.S. Dept. of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

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Oxidant Impact on Ponderosa and Jeffrey Pine Foliage Decomposition[1]

J. N. Bruhn, J. R. Parmeter, Jr., and F. W. Cobb, Jr.[2]

Litter decomposition was studied on four plots ocated along the oxidant dosage gradient in the an Bernardino Mountains (SBNF). Precipitation ecreased with decreasing oxidant dosage along his gradient, while forest floor-level solar adiation and temperature increased. Ponderosa Pinus ponderosa Dougl.) and Jeffrey pine (Pinus effreyi Grev. & Balf.) dominated the most and east severely impacted sites, respectively. ylon mesh envelopes of fresh-fallen litter were xchanged among healthy and sick trees on the our study sites. Decomposition was measured as ercents overall and nutrient (N, P, K. Ca and Mg) eight loss.

During the first two years of decomposition, s rate at each site was directly related to ecipitation and oxidant dose. While site mois- ure apparently dominates litter decomposition, idence suggests that oxidant injury to live eedles is directly related to the rate at which ey decompose. One year weight loss of ponderosa ne litter was negatively correlated (P .05) with e oxidant injury scores (O.I.S.)(Miller 1973) litter source trees. One year weight loss by tter of both species was negatively correlated .05) with the O.I.S. of litter destination ees.

Live needle internal microflora may be initi- ed in the foliar bud and can be thought of as oneers in a succession of microorganisms re- onsible for litter decomposition. Microbial pulations involved in foliage decomposition re studied via incubation of surface-sterilized ve and litter needles on water agar. Eight ees from each of two central Sierra Nevada sites, anislaus National Forest (SNF) and Blodgett perimental Forest (BEF), were included for com- rison with the 15 SBNF study trees. Both taxo- mic richness and population density increased th needle age. Both parameters increased simi- rly with age on all four SBNF sites. However, th parameters increased faster on the somewhat ss oxidant-impacted BEF, and both parameters veloped fastest on the least oxidant-impacted te (SNF).

Because not all fungi recorded in incubation studies were identified, they are individually referred to as categories rather than species. Live SNF foliage yielded approximately twice as many fungus categories (60) as foliage from any other site. The two BEF plots harbored a few more categories (29 and 32) than did HV (27), the healthiest SBNF site. HV, in turn, provided more categories than any other SBNF site (15 to 20). Similar effects were not evident in forest floor litter. Oxidants apparently affect live needle microflora in two ways. By reducing needle longevity, internal microflora development is prematurely truncated. It also seems likely that oxidants further reduce the variety of fungi colonizing live pine foliage by eliminating susceptible species. Insofar as community functional properties are stabilized by a combination of species adaptability and community diversity, reduction of live foliage microfloral diversity by oxidants is viewed as weakening the functional stability of these communities. The significance of such weakening is unknown.

In a growth chamber experiment, propylene oxide-sterilized pine needles were incubated on moist forest floor organic matter from either the SNF or one of the SBNF sites. No meaningful differences in weight loss developed between treatments over 22 weeks, showing that oxidants to date had not significantly impaired the abilities of study-site microflora to cause litter weight loss. In a second growth chamber experiment, propylene oxide-sterilized pine needles were incubated on a uniform moist forest floor organic matter mixture in either filtered air or filtered air enriched with 20pphm ozone 8 hours daily for 14 weeks. The weight loss difference between treatments did not reach significance (.05 P .01). Any effect in the field would be slight and probably limited to surface litter during moderate to severe oxidant episodes.

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Integrated Lake-Watershed Acidification Study[1]

Carl W. Chen and Robert A. Goldstein[2]

OBJECTIVES

The Integrated Lake-Watershed Acidification Study (ILWAS) was designed to determine the ecological effects of acid rain under natural conditions (EPRI, 1979, Goldstein et al., 1980). Since the most widely reported effect of acid rain has been the acidification of lake water leading to elimination of fish, it is of interest to learn how and why the ecosystem becomes acidified by acid rain.

Three forested watersheds (Panther, Woods, and Sagamore) within 15 km of each other in the Adirondack Park region of New York were selected for investigation. Each watershed has different configurations and characteristics. Principle hypothesis of the study is that these differences may lend to different pH dynamics, i.e., Panther Lake alkaline, Woods Lake acidic, and Sagamore Lake in-between.

This research will produce a comprehensive data base for the three watersheds covering a period of almost 4 years, a series of interpretive reports, and a calibrated and verified mathematical model. The wealth of understanding gained and the mathematical model developed will be readily applicable to other lake basins.

APPROACH

ILWAS couples field investigation with theoretical modeling. The interactions between the model and the field research are practiced in an interactive manner, each influencing and strengthening the other. Other research findings on mechanisms and rates of acidification processes are integrated into the model formulations.

FIELD PROGRAM

The watershed ecosystem is envisioned to comprise a cascade of basic compartments: atmosphere, canopy, snowpack, catchment, soil layers, bogs, stream segment and lake. These are the compartments that the acid rain must pass through before it reaches lake outlet. As it passes through each compartment, biogeochemical processes acting in series and in parallel will produce or consume acids and will release chemicals that shift the pH and other chemical equilibrium.

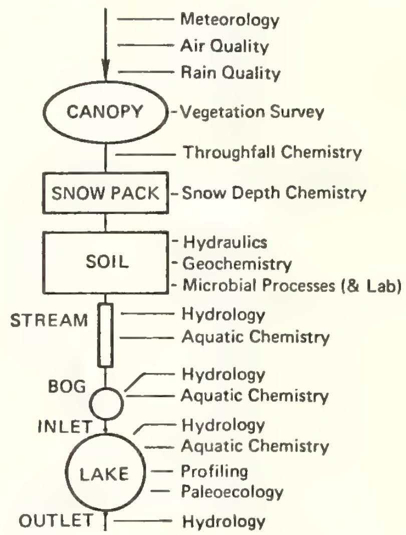

Figure 1--Field Program Components

Field surveys are being conducted to characterize the properties of the basic ecosystem compartments in each watershed. At selected locations, measurements are made for ambient air quality, the quantity and quality of waters that move through the system from tree top to lake outlet (see fig. 1). Data are collected monthly, weekly, synoptic and once only, depending on the parameters and their temporal variability. The field program began in 1977 and will be completed in 1981.

MODELING

The model organizes the data into an integrated theoretical framework (Goldstein et al., 1980). The model also serves as a vehicle to check the consistency of theory and data from rainfall quantity to lake outlet quality. Eventually, the model may provide scientific answers to such management questions as: What will and will not happen if a certain air quality standard is imposed, and if the acidity of precipitation is increased or decreased.

The model flowchart shows the computation sequence (fig. 2). The model calculates dry deposition as a function of ambient air quality and simulates the quantity and quality of water in throughfall, soil horizons, bogs, stream, lake, and lake outlet (Chen et al., 1978). All important acidification processes are included in the model.

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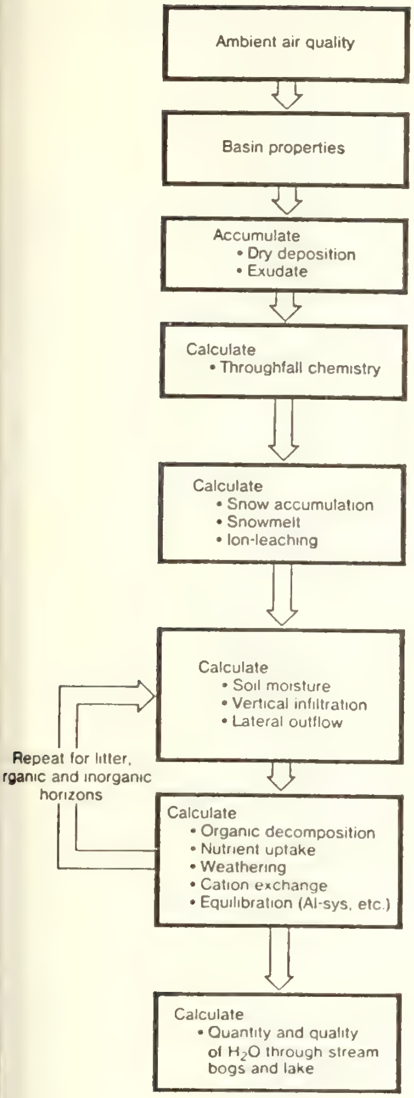

igure 2--Model Flowchart

The model uses a network of compartments to ccount for spatial variability of ecosystem. It pdates meteorological conditions daily and ambient air quality weekly. The calculations are erformed on a daily time step to simulate the ynamic responses of ecosystem throughout years. raphic outputs are provided to facilitate interretation.

PRELIMINARY FINDINGS

Data indicate that the H^+ deposition rates are easonal and are approximately the same for all hree watersheds (Johannes and Altwicker, 1980). he seasonal pattern of H^+ deposition seems to ollow that of SO_4 deposition (Johannes, 1980). he deposition rates of various ions in acid rain s measured at seven ILWAS stations correlate ell with those measured at the nearby MAP3S tations. This is significant because it suggests hat acid rain data from regional monitoring staions may be used to perform preliminary calculaion of acid rain effect for a new site.

The pH at Panther Lake inlet is normally 7.3 to 7.5 throughout the year. The pH at the outlet is similar except during the snowmelt periods. During that period, pH drops to as low as 5.0. Something must have happened in the lake. Alternatively, it was argued that the inlet was only a small spring, not representative of all inflows.

The pH profiles measured in the lake show that only surface water is acidified during the period of snowmelt (Hendrey et al., 1980). What is the source of H^+ ions that acidify the lake surface?

To resolve the puzzle, the model was used to help trace the source of water at the outlet. The model was first calibrated to the Panther Lake basin (Chen and Goldstein, 1980). After that, precipitation falling directly on lake surface is set to zero. This allows estimation of the contributions of this input to the total observed outflow. Approximately two-fifths of the peak flow can be accounted for by the direct precipitation to the lake surface. During that period, lake water is inversely stratified with respect to temperature. Direct precipitation which has a pH of 3.8 to 4.2 quite possibly is deposited right on the surface to acidify the lake surface water (pH 5.0). Another possible explanation is surface runoff resulting from snowmelt which has a high acidity (Galloway et al., 1980).

The significance of the capability to manipulate the model to examine the effect of a single process on the integrated response of the ecosystem should not be overlooked.

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Photosynthesis and Stomatal Response to Light and Temperature in Ponderosa Pine Exposed to Long-Term Oxidant Stress[1]

Patrick I. Coyne and Gail E. Bingham[2]

Seasonal courses (May to October 1977) of ross photosynthesis (calculated from $^{14}CO_2$ upake) and stomatal conductance were characterized s a function of light and gross and net photoynthesis were characterized as a function of emperature (May and July 1978) in a stand of onderosa pine (Pinus ponderosa Laws.) in the San ernardino National Forest. The CO_2 diffusion athway was partitioned into its stomatal and esidual (mesophyll, carboxylation, excitation) esistance components for conditions of light aturation and 20 C. These trees have experinced long term oxidant fumigations from Califoria's South Coast Air Basin since their establishent following fire in the mid-1950's. Nine trees ere stratified for comparative studies into three ronic injury classes (I - slight injury, II - oderate, III - severe) having similar oxidant ijury symptoms based on the scoring system of . R. Miller.

Maximum or light saturated gross photosynetic rates (P_{max}) and photochemical conversion fficiencies $(dP/dI)_{I=0}$ were highest in the curent needles and decreased with increasing neele age and with season. Differences among neele age classes within an injury class diverged s the season progressed indicating an accelerion of senescence by ozone. Maximum stomatal onductances (C_{max}) and stomatal sensitivity to icreasing light $(dC/dI)_{I=0}$ during opening folwed a similar trend to P_{max} and dP/dI except the current needles in which C_{max} and dC/dI ere highest in the severely injured trees. This iggests a possible factor contributing to diferential ozone sensitivity in this stand. The itio of the stomatal resistance for CO_2 (r'_s) to ie total resistance (r', stomatal+residual) ecreased with oxidant injury, increasing needle je, and season suggesting that loss of photonthetic capacity resulted more from limitations the chloroplasts than from resistance to CO_2 ffusion through the stomata.

Temperature optima (T_{opt}) for photosynthesis re similar in all injury classes and averaged about 20°C in May and 25°C in July. Light respiration (estimated as $P_{gross}-P_{net}$) was highest in healthy young needles and increased with temperature from 5°C to T_{opt} and then leveled off between T_{opt} and 35°C. Although light respiration was inversely related to oxidant injury, the ratio of P_{net}/P_{gross} tended to decrease with oxidant injury. Apparently oxidant stressed trees not only had reduced rates of CO_2 fixation, but retained a smaller proportion of assimilated carbon after respiration losses. Summary data for select parameters are compared in Table 1.

Table 1--Comparison of select parameters normalized by dividing each mean by the maximum mean value in each column.

Injury Class	Needle Age	1977 Means P_{max}	1977 Means C_{max}	1977 Means r'_s/r'	July 1978 $P_{gross}-P_{net}$
I	0	1.00	0.89	1.00	1.00
	1	0.61	0.84	0.80	0.60
	2	0.32	0.62	0.59	0.35
II	0	0.92	0.92	0.82	0.95
	1	0.53	0.75	0.71	0.51
	2	0.17	0.38	0.40	0.18
III	0	0.79	1.00	0.59	0.94
	1	0.35	0.57	0.45	0.35
Max. Value[1]		8.30	0.24	0.29	2.46

[1]Parameters defined in text. Units: P, mg CO_2 $g^{-1}h^{-1}$; C, cm s^{-1}; r, s cm^{-1}; age in years.

The differential response in photosynthesis and stomatal conductance among these field-grown ponderosa pine trees growing in a common environment indicated the presence of ecotypic variation in ozone sensitivity. The differences among injury classes were manifest as an acceleration of the normal decline in CO_2 fixation and stomatal conductance associated with needle aging. Particularly evident were the premature senescence and abscission of needles occurring at about the time gross CO_2 uptake dropped to 10 percent of the potential for class I current needles without foliar injury symptoms. This occurred at integrated incident ozone doses as low as 450 ppm-h in severely injured trees (class III) or as high as 800 ppm-h in slightly injured trees (class I).

A probable scenerio for oxidant effects can be described. As foliar injury symptoms increase, photosynthetic capacity and net carbon accumulation per unit leaf mass or area, mass and area per needle, needle mass per unit area, and number of needle whorls retained per tree decline. These factors contribute to the steady loss of tree vigor, weakening them to the point of vulnerability to pathogenic organisms such as root rotting fungi and bark beetles.

[1]Presented at the Symposium on Effects of r Pollutants on Mediterranean and Temperate rest Ecosystems, June 22-27, 1980, Riverside, lifornia, U.S.A.

[2]Plant Physiologist, Southern Plains Range search Station, USDA/SEA/AR, Woodward, Okla.; d Environmental Scientist, Lawrence Livermore boratory, Livermore, Calif.

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The Effect of Air Pollution on Western Larch as Detected by Tree-Ring Analysis[1]

Carl A. Fox and Thomas H. Nash III[2]

The number of publications in recent years dealing with the effects of air pollution on plants has been voluminous. A vast majority of these have dealt with the effects of short-term (hours or days) fumigations on plant response. In contrast to these studies, there is relatively little information on the long-term, cumulative effects of air pollution over decades. To examine these long-term effects, a dendroecological (tree-ring) analysis was employed to assess the growth response of western larch (*Larix occidentalis* Nutt.) to sulfur dioxide. Utilization of dendroecological techniques provided a means for quantitatively removing the effect of climate on the growth response of larch and, thus, permitted an examination of the residual growth response in terms of local site factors, specifically sulfur dioxide.

Five western larch study sites were located in the Columbia River Valley near the lead-zinc smelter at Trail, British Columbia. This particular location represents a unique study area in that the sulfur dioxide gradient has been well documented, both over space and time, since smelting activity began in 1896.

Sulfur emissions from the smelter increased in the early 1900's, reached a maximum in 1930, and resulted in a concommitant decrease in annual tree growth. After 1930, sulfur emissions decreased dramatically with the implementation of pollution abatement measures. However, the growth response of western larch to the decreased sulfur emissions was not immediate, and reflected the low frequency nature of the variance of the sulfur dioxide effect on tree growth.

Correlation and regression analyses were utilized to develop multivariate models for the larch study sites sampled at varying distances from the Trail smelter. Climatic models developed for the control site (tree-ring) chronology were applied to site chronologies located within the sulfur dioxide affected area to remove the effects of climate on tree growth and examine the residual response of the system. The pattern of the residuals closely resembled the sulfur emissions from the smelter with the most negative residuals occurring when sulfur emissions were greatest.

Further regression modeling identified the relative importance of sulfur emissions, prior year's growth, temperature, and precipitation to annual tree growth. In those sites closest to the smelter, sulfur emissions accounted for the greatest proportion of the variance calibrated by the regression models. As distance from the smelter increased, the variance attributable to sulfur emissions decreased in each site model. In all of the site models, temperature, particularly summer temperature, appeared to be a primary limiting climatic factor. Prior growth also accounted for considerable variance in the models with precipitation variables appearing to be of lesser importance in explaining the variance of the site chronologies.

The results of this study demonstrate the applicability of tree-ring analysis in identifying and quantifying the long-term effects of air pollution on forest communities. It also provides a basis for examining the interrelationship between air pollution, climate, and tree growth.

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[1]Presented at the Symposium on Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, June 22-27, 1980, Riverside, California, U.S.A.

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Acid Rain: Threshold of Leaf Damage in Eight Species from a Forest Succession[1]

B.L. Haines, M. Stefani, and F. Hendrix[2]

Eight plant species were subjected to arti- icial acid rains of pH 2.5, 2.0, 1.5, 1.0, and .5 in order to determine the threshold for and ymptoms of damage. In a previous study arti- icial acid rains of pH 5.5, 4.5, 3.5, and 2.5 ailed to produce symptoms of damage. The pre- ent study was designed to extend the pH range. he plants were Erechtites, Robinia, Pinus, uercus, Carya, Liriodendron, Acer, and Cornus rom the Forest Service's Coweeta Hydrologic aboratory near Franklin, North Carolina. Du- licate 0.01 ml drops of each of the 5 simulated cid rain solutions were applied to a single ature leaf on each of two plants of seven spe- es. The entire experiment was performed twice. Pinus needle tips were immersed in the solu- ons. The sizes of necrotic spots are shown in g. 1. Droplets of pH 2.0 produced brown nec- tic spots on all species except Pinus while oplets of pH 1.0 produced necroses on leaves of l species examined. Pinus needles were dam- ed at pH values between 1.0 and 0.5. Damage was nfined to younger needles and was evidenced by owning and collapse. For angiosperms the sizes necrotic spots increased with decreasing pH. is suggests that the leaf has some buffering pacity which was progressively overcome by creasing droplet acidity. Comparison of re- lts with literature suggests that developing aves are more easily damaged than are mature aves used in this study. No successional ends in susceptibility were observed.

[1]Presented at the Symposium on Effects of Air llutants on Mediterranean and Temperate Forest osystems, June 22-27, 1980, Riverside, lifornia, U.S.A.

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The volume weighted average rainfall pH for Coweeta is 4.6 with observations ranging from 3.2 to 5.9. Because the pH scale is logarithmic with a decrease in 1 pH unit corresponding to a 10-fold increase in the H^+ concentration, it is apparent that a 100-fold increase in the volume weighted average concentration of H^+ at Coweeta would change the pH from 4.6 to 2.6 which is near the threshold of damage. However, the extremes may be far more critical than the volume weighted average. With the lowest pH value recorded for Coweeta being pH 3.2, merely a 10-fold increase in acidity to pH 2.2 in a single spring or summer storm seems likely to bring damage or death to mature leaves of the flowering plants at Coweeta.

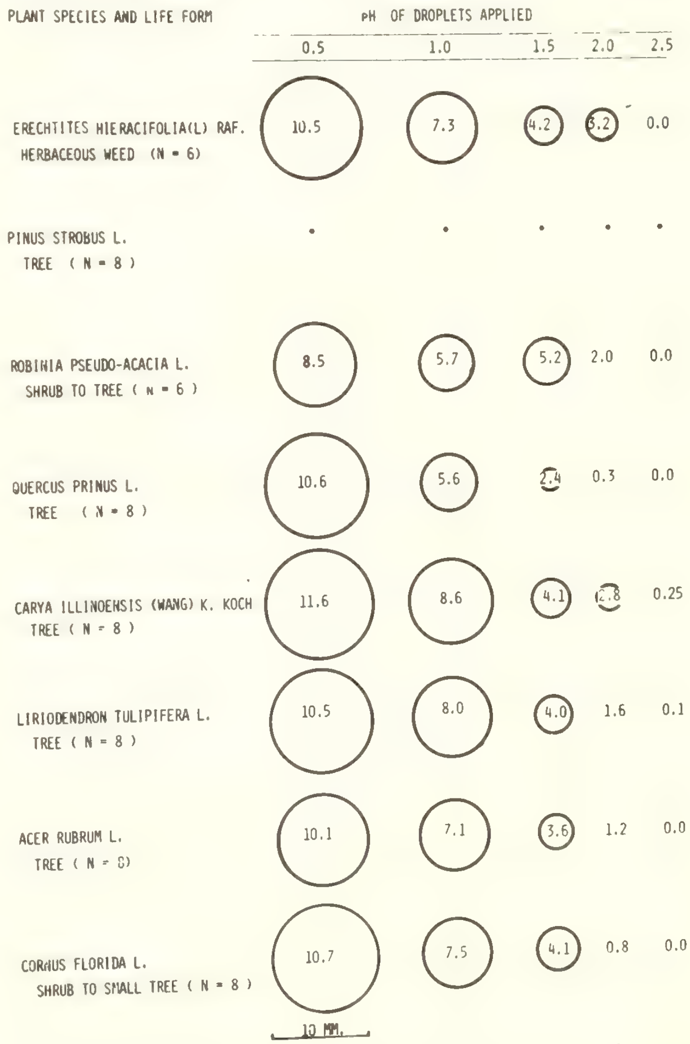

Figure 1. Average diameter in mm of necrotic spots on leaves subjected to droplets of 5 pH levels. (*) Spot diameters not measured on needles, see text for description of damage.

Prioritization of Research on Air Quality Related Resources of the National Parks[1]

E. A. Howard, L. M. Boyd, W. M. Brock, D. W. Morse, S. S. Shin and K. L. Steel-Sabo[2]

The National Park Service (NPS) has the legal responsibility and authority to preserve and protect the resources of lands under its jurisdiction. Air pollution has been recognized as a significant threat to the parks and the 1977 Amendments to the Clean Air Act provided the Service the authority and responsibility to protect resources that are air quality related. The NPS Air Quality Office intends to conduct research programs to determine air pollution effects, to emphasize the use of sensitive receptors to detect effects, as well as to ensure that scientific evidence is readily available when NPS must make determinations of adverse effects. These efforts are subject to time and funding limitations and therefore guidelines on setting research priorities are being developed.

The first step in establishing cause and effect relationships is to identify the pollutants that may affect park resources (fig. 1). Pollutants from existing or planned sources may be identified by monitoring or estimated from permit requirements. If sources are not known, pollutants must be identified through some early warning process or on the basis of the potential development of regional natural resources. Existing sources of air pollutants that may affect the natural or cultural resources of park units must be ranked according to pollutant type, concentration, frequency, and duration of exposure of the resource. The ranking must also incorporate the estimated lead time before new pollutant sources begin operation. The identification and ranking of pollutant sources is necessary to economize the search for potential effects.

The identified pollutants are then used as a basis of comparison between the list of resources present on a park unit and the literature or current research information on resource susceptibility (fig. 1). The presence or absence of information on park resources must be incorporated into the setting of priorities. If these data are unavailable, obtaining information on air quality related resources may be the most pressing need. If the resource inventories are available, then the information from these inventories is used in the comparison between resources present and those that are susceptible to the effects of air pollution. The availability of current research information or literature on susceptibility must be similarly considered in establishing research priorities. Time constraints on recovering information or research results on air quality effects on natural ecosystems has prompted the development of a quick access annotated bibliography that uses a coding system based specifically on natural and cultural resources of NPS units. The bibliography has been used on several occasions to provide lists of references in support of litigation and testimony for hearings.

Setting priorities for research on air quality effects is altered by other influences and constraints (fig. 1). Funding and time limitations must be incorporated into the prioritization. Insufficient funding may cause postponement of the highest priority research until these requirements can be integrated into the budget cycle. Time constraints also have considerable influence on priority setting. Substantive scientific data on air quality effects cannot be produced within the short time schedules of hearings or litigation. The timing of the budget cycle creates difficulty in obtaining sustained funding for long-term effects research. Political requirements at the Washington level may override the regional prioritization. The setting of priorities must be continually updated in conjunction with any change imposed by these influences or constraints.

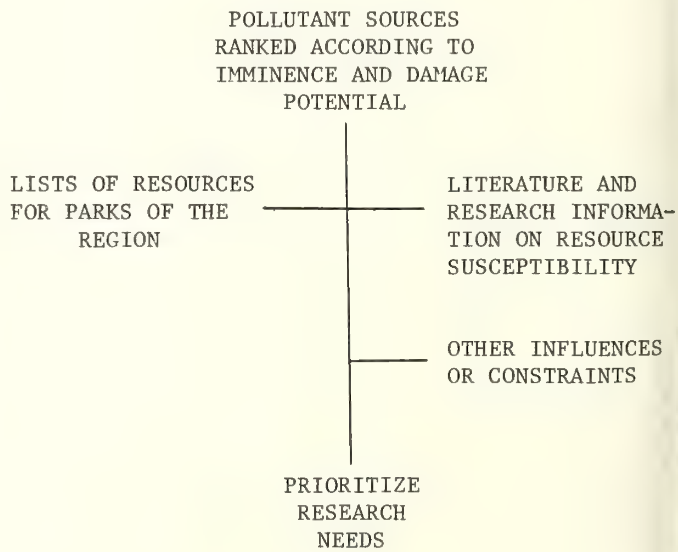

Figure 1--Considerations in setting research priorities for air quality related resources.

[1]Presented at the Symposium on Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, June 22-27, 1980, Riverside, California, U.S.A.

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Estimation of Adverse Effects of Air Pollution on Danish Forests[1]

Ib Johnsen[2]

Effects of air pollution on Danish forests do robably only occur under conditions, where SO_2, IO_x and/or O_3 are present together, thus resulting in synergistic action on the leaves. The aximum observed monthly average urban immission f NO_x and SO_2 are within the range for synergistic action hereof. In rural regions only the ost sensitive species may be affected by combiations of SO_2, NO_x and O_3. Oxidants, and O_3 in articular, probably play a stronger role in ural areas situated in the outer periphery of ities. Here levels exceeding the values at hich effects on rather sensitive species occaionally occur during summer time. Unstable uperadiabatic conditions combined with high nsolation lead to high O_3 formation rates, and igh ground level SO_2/NO_x levels are observed hen high stack emissions are transported to the round relatively close to the source.

Fluorides are only of importance in very retricted areas around brick factories, fertilzer industries etc., and of minor significance n relation to Danish forestry.

Heavy metals and hydrogen ions result in ndirect effects as adverse effects on the nutrint status of the soil and the soil microbial rocesses. The map shows areas of Denmark shaded areas) where the soil is believed to be ost vulnerable to acid precipitation; it is easonable to believe that these areas are concident with those expected to be most affected y increasing heavy metal levels in top soil due o atmospheric fallout. The most vulnerable oils are intermediate between the very podolised soils of the alluvial plains (Western utland) and brown earths/clayish soils with high uffer capacity, and are characterized by their igh content of moraine sand.

[1]resented at the Symposium on Effects of Air ollutants on Mediterranean and Temperate orest Ecosystems, June 22-27, 1980, Riverside, alifornia, U.S.A.

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Areas of woodland in Denmark related to species, 1976. (Numbers in 1000 ha.)

Fagus silvatica	75	Res.
Quercus robur	25	Res.
Fraxinus excelsior	9	Sens.
Acer psuedoplatanus	5	Res.
Other deciduous spp.	24	
Deciduous total	138	
Picea abies	173	Sens.
Picea sitchensis		Sens.
Abies spp.	27	Sens.
Pinus mugo	30	Res.
Other coniferous spp.	46	
Coniferous total	276	
Woodland total	414	

Immission levels and threshold values

	SO_2	NO_x	O_3	F^-
	(μgm^{-3}, diurnal means)			
Urban	40-100	50-100	25-50	0.5-5
Rural	10-40	5-20	25-200	0.2-0.5
Single	250	500	100	1
	100	50		
Comb.		50	50	
	100		50	

Figure 1--Areas of Denmark (shaded areas) dominated by moraine sand deposits.

Changes in Southern Wisconsin White Pine Stands Related to Air Pollution Sensitivity[1]

David F. Karnosky[2]

Fifteen eastern white pine (Pinus strobus L.) sample plots consisting of a total of 1523 trees were established within a 13 km radius of the coal-burning 1054 MW Columbia Generating Station, located 40 km north of Madison, Wisconsin. The sample plots were established in 1971 and observed frequently during the growing season for 4 years and then annually at the end of each growing season for the next 5 years. These plots consisted of plantations with trees having uniform ages within each plantation but with trees ranging in age from 10 to 40 years old across the 15 plots. Baseline study during the 4 years before the plant began operation in 1975 showed that some 10 percent of the white pine trees were sensitive in some degree to ambient air pollution as determined by the presence of needle tipburn and/or chlorotic dwarf symptoms in one or more years. The sensitive trees occurred randomly in the plots.

The most common type of air pollution symptom found in the baseline study was tipburn consisting of reddish brown dieback (0.1 to 3 cm in length) on first-year needle tips. The severity of symptoms varied from tree to tree and from year to year. The most severely affected trees had stunted tops, short needles, poor needle retention, and were characteristic of an air pollution-induced syndrome called the chlorotic dwarf disease. However, chlorotic mottling of new needles, common to the chlorotic dwarf disease, did not occur. Tipburn symptom development usually began during the early summer when the new needles were elongating. Thus, trees began showing symptoms in early to mid June, and symptoms developed throughout the growing season.

Continuous air monitoring for sulfur dioxide (SO_2) and ozone (O_3), begun in 1973 and continued to the present time, revealed the common occurrence of SO_2 and O_3 concentrations in the range of 0.4 to 5.0 pphm for 1 to 3 hours during the summer months. Maximum one-hour averages recorded during the study were 11 pphm SO_2 and 13 pphm O_3. These levels, while low in terms of air quality standards, have been shown to be within the range of concentrations of these pollutants reported to injure genetically sensitive eastern white pine trees in controlled fumigations.

During the 5 years since the power plant began operation, there have been no detectable differences in the occurrence or severity of symptoms. With only a few exceptions, the same trees have shown symptoms after the plant began operation as before it started. However, mortality has reduced intermediate genotypes (those injured in 1 or 2 years of the 9 year study) by 4.7 percent and the sensitive genotypes (those injured in 3 or more years) by 10.4 percent (Table 1). In comparison, only 2.0 percent of the tolerant trees have died during the course of the study. Most of the mortality of the sensitive genotypes was apparently due to their being slower growing and thus unable to compete for light, water, and nutrients with their neighboring trees. As a result, the white pine stands studied are undergoing a gradual transition towards having air-pollution tolerant genotypes dominate.

Acknowledgments: This study was supported in part by Grant R803971, Environmental Protection Agency, and by the Wisconsin Public Service Corp., the Madison Gas and Electric Co., the Wisconsin Power and Light Co., and the College of Agricultural and Life Sciences, University of Wisconsin.

Table 1--Mortality over a 9-year period of eastern white pine trees differing in air pollution sensitivity.

Air Pollution Sensitivity[1]	Original Number Of Trees	Number That Have Died	Percent Mortality
Tolerant	1369	27	2.0 pct.
Intermediate	106	5	4.7 pct.
Sensitive	48	5	10.4 pct.
Totals:	1523	37	2.4 pct.

[1]The sensitivity rankings were based on the following: tolerant trees did not have air-pollution-induced tipburn symptoms during the course of the study; intermediate trees had symptoms for 1 or 2 years; and sensitive trees had symptoms for 3 or more years.

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Effect of O_3 and $O_3 + NO_2$ on Growth of Tree Seedlings[1]

Lance W. Kress[2]

Seedlings of 10 eastern forest tree species were :xposed to 0.05, 0.10, or 0.15 ppm O_3 and seedlings ·f 7 tree species were exposed to 0.10 ppm O_3 and/or ·.10 ppm NO_2 in 6 hr/day exposures for 28 consecu-ive days. The exposures were performed when the eedlings were 2—4 wk-old in indoor exposure hambers of the CSTR design.

The Environmental Protection Agency has deter-ined that the threshold for significant growth ffects due to extended O_3 exposures (7 hr daily vg. for 2 mo) for sensitive vegetation is between .06 and 0.10 ppm. Three species in this study ex-ibited a threshold for significant suppressions in hat range, while three other species exhibited a hreshold for significant effects between 0.10 and .15 ppm (Table 1). However, two species exhibited threshold for significant growth suppressions at r below 0.05 ppm. Those two species, loblolly pine nd American sycamore, are probably the most im-ortant of the species tested to the forest industry. he significant effects at 0.05 ppm O_3 were not ccompanied by foliar injury.

In previous studies there have been indications hat low concentrations of NO_2 might be stimulatory o plant growth or alleviate O_3 phytotoxicity. imilar indications were noted for some of the tree pecies in this study. Two species (white ash and reen ash) exhibited greater growth in the NO_2 reatment than the control, and the only significant nteractive effects were significantly less than dditive (sweetgum and white ash).

Stimulations of growth at low O_3 concentrations ave been noted in the past, and some species ex-ibited growth stimulations in this study (Table 1). owever, apparent growth stimulations appear to be ependent in part on the plant species and the arameter being evaluated.

The relationship that these data have to field onditions is not clear. This study demonstrates e potential for adverse effects at pollutant con-entrations below the current NAAQS, but future esearch will have to determine whether such effects an be detected in the field.

Table 1. Height growth and dry weight expressed as percent of control for seedlings of 10 tree species exposed to 0.05, 0.10, or 0.15 ppm O_3 for 6 hr/day for 28 consecutive days.

Species	Treatment	Percent of control: Height growth	Dry weight: Top	Dry weight: Root
Loblolly Pine	C	[1]100a	100a	100a
(Pinus taeda L.)	5	82 b	85ab	90ab
	10	73 b	79 b	72 bc
	15	59 c	74 b	64 c
Pitch Pine	C	100a	100a	100a
(P. rigida Mill.)	5	96ab	94a	84ab
	10	87 b	83a	77ab
	15	74 c	78a	68 b
Virginia Pine	C	100a	100a	100a
(P. virginiana	5	95a	98a	120a
Mill.)	10	89a	97a	93a
	15	86a	87a	86a
Sweetgum	C	100a	100a	100a
(Liquidambar	5	109a	91ab	88ab
styraciflua L.)	10	71 b	76ab	65 bc
	15	55 b	60 b	52 c
Sycamore	C	100a	100a	100a
(Platanus	5	104a	84a	57 b
occidentalis L.)	10	73 b	43 b	27 b
	15	79 b	36 b	19 b
Green Ash	C	100a	100a	100a
(F. pennsylvanica	5	98ab	86ab	86a
Marsh.)	10	76 bc	71ab	75a
	15	70 c	64 b	75a
White Ash	C	100a	100 b	100ab
(Fraxinus	5	112a	125a	111a
americana L.)	10	91a	92 b	87 b
	15	85a	83 b	81 b
Willow Oak	C	100a	100a	100a
(Quercus phellos	5	99a	99a	94a
L.)	10	96a	92a	83a
	15	81 b	89a	83a
Sugar Maple	C	100 b	100a	100ab
(Acer saccharum	5	95 b	88a	161a
L.)	10	108a	90a	116ab
	15	88 c	58 b	69 b
Yellow Poplar	C	100 b	100 b	100a
(Liriodendron	5	160a	147a	133a
tulipifera L.)	10	108 b	111ab	96a
	15	88 b	108 b	121a

[1]Values for each column/species followed by the same letter are not different at p = 0.05 according to the Duncan's New Multiple Range Test.

[1]Presented at the Symposium on Effects of Air ·llutants on Mediterranean and Temperate Forest osystems, June 22-27, 1980, Riverside, lifornia, U.S.A.

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Impact of Oxidant Air Pollution on Ponderosa and Jeffrey Pine Cone Production[1]

Robert F. Luck[2]

Cone production by ponderosa and Jeffrey pine trees 10 cm or more in dbh was assessed on 19 plots located in the San Bernardino Mountains of southern California. These plots were established along a gradient of oxidant air pollution. Each tree was rated annually using an oxidant air pollution index based upon the number of year classes of needles retained, their chlorotic condition, their length and the amount of branch mortality present. This rating was made independently in the upper and lower crown for each tree. Other tree characteristics, e.g., age, dbh, height, were also measured once during the course of the 6 year study. Cones were visually counted within the crown of each tree each September and October.

Although severe oxidant air pollution injury was associated with reduced cone production, the most important correlate with cone production was crown class, i.e., the position of a tree's crown relative to those of its neighbors. Dominant trees bore the greatest proportion of cones. In ponderosa pine dominant trees comprised 32 percent of those present on the 19 plots but bore 80 percent of the cones. When the dominant and codominant crown classes were combined they comprised 58 percent of the ponderosa pines but bore 96 percent of the cones. Jeffrey pine showed a similar pattern. In both Jeffrey and ponderosa pine, cone production increased significantly with age (H_o:b=0: ponderosa pine; dominant: $\hat{y} = -92.33 + 1.86$ (Age), $r^2 = 0.811^{**}$; codominant: $\hat{y} = -74.48 + 1.077$ (Age), $r^2 = 0.4216^{*}$: Jeffrey pine; dominant: $\hat{y} = 4.74 + 0.434$ (Age), $r^2 = 0.765^{**}$; codominant: $\hat{y} = -8.28 + 0.243$ (Age), $r^2 = 0.7456^{**}$).

Three patterns were observed: (1) In dominant Jeffrey pines 130 years or older fewer severely injured trees bore cones than uninjured ones (1b $F_{(4,25)} = 11.98$, $p < 0.05$); (2) in dominant ponderosa pines 130 years or older severely injured trees bore fewer cones/tree than uninjured ones (2a $\chi^2_{(4)} = 21.07$, $p < 0.005$); and (3) in both dominant and codominant Jeffrey and ponderosa pines severely injured trees bore significantly fewer cone crops than uninjured ones during the 6 years of the study (χ^2's values < 0.01 in 5 cases, < 0.05 in 1 case).

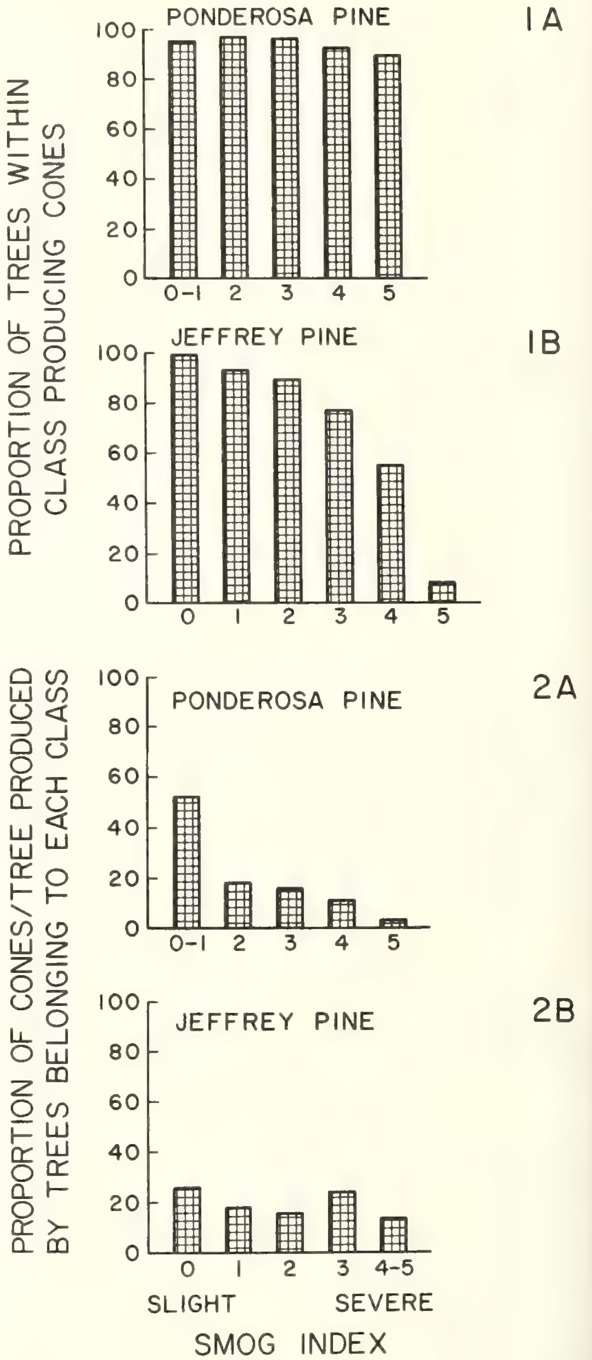

Fig. 1. Proportion of trees producing cones in a given smog class. (a) Ponderosa pine; (b) Jeffrey pine.

Fig. 2. Proportion of cones/tree borne by tree belonging to a given smog class. (a) Ponderosa pine; (b) Jeffrey pine.

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[1]Presented at the Symposium on Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, June 22-27, 1980, Riverside, California, U.S.A.

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Lichens as Air Quality Monitors[1]

P.D. Lulman
R.J. Fessenden
S.A. McKinnon[2]

The Athabasca tar sands, located in a remote region in northeastern Alberta, in the boreal forest region of Canada, contain vast reserves (approx. 600 billion barrels) of bitumen. At the present time there are only 2 companies operating in the region, producing synthetic crude oil from this bitumen, Suncor Inc. and Syncrude Canada Ltd. Suncor, which began production in 1967, emits approximately 200-300 tonnes of SO_2 per day. Syncrude, which began production in 1978 and which is located only 10 km from Suncor, has been emitting about 50-100 tonnes per day. In the next 10-20 years there is a good possibility that many more companies will begin operating in the region as well. This has lead to a concern about the effects of changes in air quality on the vegetation of the region. Since lichens are known to be more sensitive to air pollutants, particularly SO_2, than most higher vegetation, it was decided to monitor changes in lichen growth as an early warning of the impact of pollutants on all components of the vegetation.

In 1976, Syncrude Canada Ltd. installed a network of 56 permanent plots in a radiating pattern centered on the 2 operations and at distances of up to 47 km. Within each plot 20, 200 cm^2 permanent quadrats containing thalli of Parmelia sulcata or Hypogymnia physodes, 2 abundant bark lichens, were established and photographed. Most of the quadrats were established on white spruce (Picea glauca), although a smaller number were established on balsam fir (Abies balsamea) and white birch (Betula papyrifera). The photographs were projected and the surface areas of selected lichen thalli were measured. In 1979, all of the quadrats in 12 selected plots were rephotographed and the photographs analyzed as before. The objectives of this partial resurvey were (a) to measure changes in the surface area of thalli of P. sulcata, the dominant lichen species, in the 3 year period 1976-1979, (b) to test the significance of these changes as a function of distance and/or direction from the emission sources, and (c) to assess the practicability of the lichen network as a long term monitoring system for detecting air quality impacts on vegetation.

There was a significant increase in projected thallus surface area in 6 plots, a significant decrease in 2 plots, and no significant change in 4 plots. In most cases the net change in lichen surface area during the 3 year period was less than 10%. However, within-plot variability was very large with coefficients of variation commonly between 300-400%. The changes in projected thallus surface area were significantly but weakly, related to distance; the thalli closest to the emission sources increasing more in area than those at a distance, where in fact there was a net decrease in surface area on the average. Field observations indicated that there was no relationship between lichen color and/or vigor and distance and/or direction from the emission source. It was evident in a comparison of the 1976 and 1979 paired photographs that there was a significant loss of whole thalli and portions of thalli from most of the quadrats. It was not unusual for 10-20% of the thalli present in 1976 to be missing in 1979. This appeared to be primarily related to the natural process of bark exfoliation, although animal activity and insect grazing are also suspected causes.

This technique is capable of detecting significant changes in the surface area of P. sulcata thalli over a 3 year period, however, it requires careful standardization and a large number of samples due to the large within-plot variability in this characteristic. The high variability is related to the rather non-uniform growth of the P. sulcata thallus as well as the variety of natural processes causing losses of portions of the thallus. Perhaps other attributes of the thallus would make better indices of growth (or lack of growth), however, none were investigated. The extensive losses of whole thalli raise questions about the permanence of this system and hence its value as a long term monitoring system. Because the predominant reason for thallus loss is bark exfoliation, this problem is very much related to tree species. Spruce are particularly bad in this regard. There was very little thallus loss from birch or fir. Notwithstanding the above difficulties, it was concluded that there was no air quality caused damage to P. sulcata between 1976 and 1979 as inferred from the relationships between the net change in thalli surface area and distance and/or direction from the emmission sources. This conclusion is supported by field observations of lichen color and vigor.

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[1]Presented at the Symposium on Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, June 22-27, 1980, Riverside, California, U.S.A.

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Acid Precipitation in California and Some Ecological Effects[1]

John G. McColl and Mary K. Firestone [2]

Wet and dry precipitations were monitored on an event basis in 1978-9 at Berkeley and San Jose (pollution source areas in the San Francisco Bay area), Davis and Parlier (in the central agricultural and rangelands), Challenge (lower Sierran forest), and Tahoe City (on the shore of Lake Tahoe). Concentrations of thirteen ionic species and specific conductance and volume were measured (Table 1).

Acid rain (pH < 5.6) was common at all eight sites. Mean pH of storms varied from 4.24 at San Jose to 5.20 at Davis, and the lowest pH of any storm was 3.71 at San Jose. The primary cause of the acidity was probably the air pollutant NO_x, following its dissolution in wet precipitation. NO_3^- was the anion most closely correlated with H^+, and NO_3^- generally occurred in greater concentration than SO_4^{2-}.

Total dry depositions of chemical constituents between rainstorms were of the same order as total wet depositions during storms. Dry deposition during summer would greatly increase the amounts recorded in this study which was conducted in the wet season only. However, more research is needed in procedures for quantifying dry atmospheric deposition.

Although NO_3^- concentration (μg/l) and acidity (H^+ concentration, μg/l) of wet precipitation were greatest in pollution source areas, total deposition (kg/ha) of NO_3^- and H^+ were greatest in the non-urban receptor areas of Napa and Challenge; this was largely a function of the greater precipitation volumes at these two sites (Table 1). Thus ecological effects may be expected in the coast ranges and Sierras within the general east-to-west "wash-out fan" of wet precipitation, as well as within pollution-source areas.

Effects of these acid inputs to California soils are currently being assessed. These investigations on soil effects include research on both the inorganic phase of soil and on the organic/biological components.

Table 1--Mean ionic concentrations of wet precipi tation during the study period in 1978-9 (μeq/l).

Ion	SITE[1]							
	BE	TC	KE	CH	SJ	HO	DA	NA
H^+ (Lab.)	22.1	6.8	10.9	13.0	38.0	7.9	6.3	14.
Na^+	36.9	11.8	15.3	12.8	33.1	14.5	15.1	22.
K^+	1.5	0.6	1.4	2.1	1.5	1.1	1.1	1.
Ca^{2+}	6.0	4.3	8.0	10.9	12.6	3.3	5.6	4.
Mg^{2+}	9.6	1.7	3.6	7.0	9.7	3.8	5.7	5.
Fe^{3+}	0.3	0.0	0.6	0.4	0.8	0.2	0.4	0.
Mn^{2+}	0.1	0.0	0.1	0.6	0.1	0.1	0.1	0.
Cu^{2+}	0.1	0.1	0.1	0.2	0.3	0.1	0.2	0.
Zn^{2+}	0.3	0.1	0.2	0.2	0.6	0.1	0.1	0.
NH_4^+	8.0	4.1	40.0	11.9	19.1	9.7	35.5	12.
NO_3^-	13.7	6.7	43.4	19.9	16.4	11.1	22.6	16.
Cl^-	40.1	3.7	11.2	7.7	38.9	14.2	14.0	23.
SO_4^{2-}	10.2	13.3	13.8	8.6	10.0	6.2	19.0	11.
Cond. (μmho/cm)	13.9	3.9	17.4	10.6	16.2	6.4	9.6	10.
pH (Lab.)	4.7	5.2	4.7	4.9	4.4	5.1	5.2	4.
Vol. (cm)	52.7	78.0	19.7	110.7	21.0	64.9	39.7	62.

[1]BE Berkeley, TC Tahoe City, KE Kearny (field station at Parlier), CH Challenge, SJ San Jose, H Hopland, DA Davis, and NA Napa.

In the inorganic soil-chemical studies, soils covering a wide range of parent materials and age are being treated with acid inputs, and the subse quent leaching patterns of ions (including Al^{+3}, H^+, Na^+, K^+, Mg^{++}, Ca^{++}) are being determined.

The biological investigations include assessment of possible effects on the soil-plant nutrient system. The first 10-week pot-trial, using a Yolo series soil and growing barley and clover, has just been completed. Preliminary results indicate marked growth increases in treat ments where the plants were sprayed with solutior of pH 2.0 and 3.0. This result is attributed to greater additions of SO_4^{2-} and NO_3^-, and/or to increased availability of soil nutrients in these lower-pH treatments. However, spotting or leaves by acid droplets also occurred in the pH 2.0 treatments. Nitrification, denitrification and nitrogen fixation activities are being measured both the rhizosphere and non-rhizosphere soil.

[1]Presented at the Symposium on Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, June 22-27, 1980, Riverside, California, U.S.A.

[2]Associate Professor of Soil Science and Associate Specialist in Soil Microbiology, respectively, University of California, Berkeley, California, U.S.A.

Leaf Litter Decomposition in the Vicinity of a Zinc Refinery[1]

W. D. McIlveen[2]

Emmissions from a large zinc refinery in northern Ontario have been monitored for 10 years and an accumulation of zinc, copper, cadmium, arsenic and lead in the soil and vegetation surrounding the refinery complex has been documented. It was considered that decomposition of leaf litter as a part of the nutrient cycling process might be a convenient method to monitor the initial impact of these metals on the environment. This investigation was undertaken in the fall of 1977. Nylon mesh bags containing 10 g (oven-dry weight) of trembling aspen (*Populus tremuloides*) were set out at several locations around the refinery. Two sources of aspen foliage were utilized including foliage from a control location and contaminated foliage collected near the refinery. The exposure locations for the litter bags included three sites in close proximity to the refinery, (Plot A, B, C) one site 2.2 km from the refinery (Plot D) and one at a control location (80 km southwest of the refinery)(Plot E).

The litter bags were allowed to over-winter and triplicate bags of each litter type were collected in May, June and August of 1978 and in May, July and August in 1979. Microarthropods were extracted from the bags in modified Tulgren funnels in the laboratory. The litter was then dried to determine the leaf weight loss and processed for chemical analysis.

It was found that the rate of decomposition of the leaf litter was lower at sites nearest to the refinery and that contaminated foliage decomposed more slowly than control foliage at all sites. The microarthropod population was dominated by mites and springtails. The number of microarthropods was generally lower at the sites nearest to the refinery and was also lower in the litter bags containing the contaminated foliage. The numbers of microarthropods appeared to fluctuate with moisture content of the litter. It was found that the concentrations of zinc, copper, cadmium, lead, arsenic, iron, sulphur and selenium in the leaf litter increased with time at the sites nearest to the zinc refinery but only a slight increase was noted at the more distant sites.

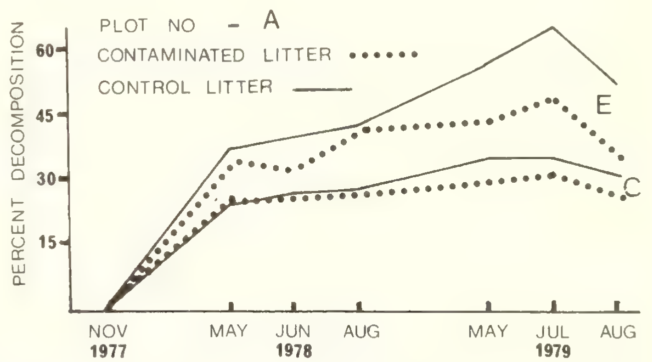

Figure 1. Pattern of decomposition of two types of leaf litter at two sites.

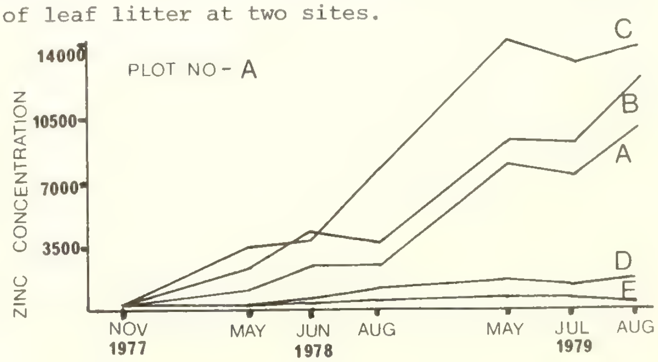

Figure 2. Zinc accumulation is typical of metal accumulation in leaf litter.

[1]Presented at the Symposium on Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, June 22-27, 1980, Riverside, California, U.S.A.

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Effects of Chronic Air Pollution Stress on Allocation of Photosynthate by White Pine[1]

S. B. McLaughlin, R. K. McConathy, and D. Duvick[2]

Allocation of ^{14}C-photosynthate by in situ branches of nine field-grown white pine trees was studied to determine whether distribution patterns differed between trees with apparent differences in sensitivity to air pollution stress. Three trees were selected in each of three sensitivity classes which were differentiated on the basis of needle length, mottling, and duration of retention. Previous studies (Mann et al. 1980) indicated that photosynthetic potential of foliage from trees in these three classes was not significantly different. Growth ring analysis of increment cores indicated that average annual increment of intermediate and sensitive trees was 98% and 47%, respectively, of that attained by the tolerant trees (7.8 mm yr^{-1}) over the past 18 years (Fig. 1). Sensitive trees showed a marked decline in annual growth during the past 10 years.

Foliage was labelled with $^{14}CO_2$ four times during the growing season (June, July, August and November). Of the paired branches from each tree labelled on each date, one was harvested after seven days and the remainder in November at the end of the growing season. Photosynthate allocation patterns were compared by determining levels of foliar retention and allocation to nearby branches. In June when elongating needles were approximately 50% of their final length, ^{14}C movement patterns in needles of three age classes (Fig. 2) indicated that contribution of ^{14}C-photosynthate by old needles to new needle growth was occurring. This process was most rapid in tolerant trees which retained needles from two prior years and least significant in sensitive trees. Lower levels of incorporation of photosynthate into foliar tissues occurred subsequently ($\bar{X}$ = 35% in June, 27% in July, and 5% in August after seven days). There were no distinct differences in foliar retention of ^{14}C between the three sensitivity classes which could be associated with the distribution of high levels of ozone (1h avg $\geq$ 0.08 ppm) near the study area. Significant 2-year-old needle retention on tolerant trees did not extend beyond July.

Generally higher levels of transfer of ^{14}C from foliage into branches were noted in the tolerant trees throughout the growing season. Higher levels of translocation of ^{14}C-photosynthate out of 1-year-old needles than current-year needles were also found for all sensitivity classes. Enhanced current needle elongation (+25% sensitive, +10% intermediate, and +3% tolerant) compared to the previous year was associated with lower than average ozone levels and higher than average rainfall during the growing season. Data support the hypothesis that growth limitations in sensitive trees are a function of stress-induced reductions in photosynthate availability which result from reduced needle length (a function of decreased availability of carbohydrates for needle growth) and premature needle senescence. The resulting chronic decline of sensitive trees is likely a result of interactions between air pollution stress and site factors which may include secondary belowground pathogens.

Acknowledgments: Research sponsored by the U.S. Environmental Protection Agency under Interagency Agreement No. 40-740-78 and the U.S. Department of Energy under Contract W-7405-eng-26 with Union Carbide Corporation.

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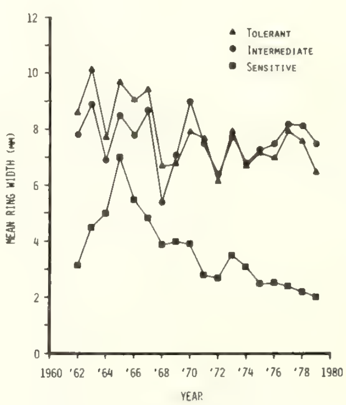

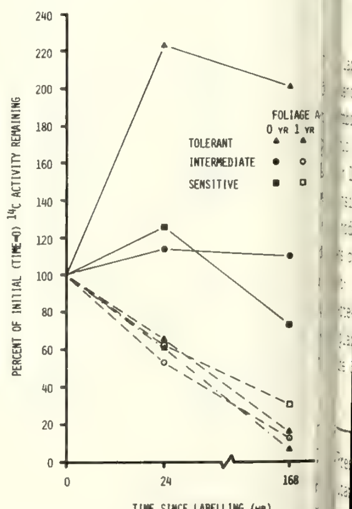

Figure 1 (left)--Average annual diameter growth of 3 trees in each of 3 sensitivity classes.

Figure 2 (right)--Distribution of ^{14}C photosynthate in foliage 0, 1, and 7 days after $^{14}CO_2$ uptake in June.

[1]Presented at the Symposium on Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, June 22-27, 1980, Riverside, California, U.S.A.

[2]Research Staff Member, Research Associate, and Technician, respectively, Terrestrial Ecology Section, Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee, U.S.A.

Effects of SO_2 and Ozone on Photosynthesis and Leaf Growth in Hybrid Poplar[1]

Reginald D. Noble
and
Keith F. Jensen[2]

Plants in the natural environment are often si- ıltaneously exposed to a combination of many atmos- ıeric pollutants. Thus it is of interest to as- ırtain the nature of interaction of these pollu- ınts on plant development and metabolism. Two pol- ıtants commonly encountered in the atmosphere which e particularly toxic to plants and would appear offer potential for interaction are SO_2 and O_3.

METHODS

Plants of hybrid poplar #207 (Populus deltoides rtr. X P. trichocarpa Torr. & Gray) were grown om cuttings under greenhouse conditions. Six ek old plants were fumigated in controlled envi- nment chambers for 12 hours per day for 24 con- cutive days. Four sets of plants were used as llows: Set 1-Controls (no fumigation); Set 2-Fu- gated with SO_2 at 0.5 ppm; Set 3-Fumigated with at 0.25 ppm; Set 4-Fumigated with SO_2 at 0.5 m plus O_3 at 0.25 ppm. At the end of the 24-day migation period, number of leaves per plant, leaf esh and dry weight and leaf area were determined. ring the later stages of the fumigation, photosyn- esis measurements were determined for single at- ched leaves from plants fumigated with SO_2 and ose fumigated with SO_2+O_3. Photosynthetic mea- rements were made at ambient CO_2 levels (300 ppm 2) and at 1000 ppm CO_2.

RESULTS

Plants fumigated with SO_2 showed little visible idence of injury while those fumigated with O_3 or combination of the two began to develop tiny ne- otic spots after 5 to 7 days of exposure. Soon er lower leaves began to abscise and by 14 days ensive injury was apparent on leaves below the ı node from the apex. Both O_3 and SO_2+O_3 treat- nts caused a reduction in the number of leaves per nt; however, the rate of leaf formation was not ected for the four groups. The number of leaves plant was lower in the O_3 treatment group than the SO_2+O_3 group, suggesting an antagonistic relationship. Fumigation tended to cause a decrease in leaf area, leaf dry weight and leaf fresh weight. This was increasingly true as the distance from the plant apex increased. Pollutant interaction evaluations revealed an antagonistic relationship between the responses to O_3 and SO_2. Ozone which retarded growth most had little or no effect on area, dry or fresh weight of leaves above node 5; however, these parameters were reduced by 25 to 40 percent in leaves fumigated with O_3 at node 9. These and related observations demonstrate that O_3 retards growth of leaves in this plant only during the later stages of their development. Ozone fumigated leaves with visible injury comparable to those fumigated with both SO_2 and O_3 contained less dry matter per unit area.

Photosynthetic measurements on controls as well as plants fumigated with SO_2 and SO_2+O_3 revealed little difference in rate of CO_2 assimilation at 300 ppm CO_2. Even in leaves of SO_2+O_3 fumigated plants where visible injury was extensive the photosynthetic rate was reduced by only 10 to 20 percent. When the CO_2 concentration was elevated to 1000 ppm CO_2 photosynthetic rates for controls, SO_2 fumigated and SO_2+O_3 fumigated leaves (with no visible injury) were elevated three-fold to approximately 35 mg CO_2 $dm^{-2}hr^{-1}$. In leaves in which injury was apparent the photosynthetic rate increases were usually less than two-fold, to a level of approximately 18 mg CO_2 $dm^{-2}hr^{-1}$ (whether the injury was severe or barely discernable).

DISCUSSION

Ozone, and O_3 in combination with SO_2 hasten senescence and promote rate of leaf drop to the extent that control plants have approximately 50 percent more leaves than fumigated ones. Fumigation with SO_2 causes no such effect. Analysis of attached leaves for treatment effects clearly shows an O_3 effect but little or no SO_2 effect. In combination these pollutants at this concentration interact in an antagonistic manner in relation to growth parameters.

Measurements of effects of fumigation on photosynthesis indicate that leaf photosynthesis is not drastically reduced even in the presence of considerable injury. It appears that injury tends to reduce leaf potential to respond to enhancement conditions more so than the ability to fix CO_2 under conditions where CO_2 may be limiting.

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[1]Presented at the Symposium on Effects of Air lutants on Mediterranean and Temperate Forest systems, June 22-27, 1980, Riverside, ifornia, U.S.A.

[2]Professor of Biological Sciences, Bowling Green te University, Bowling Green, Ohio; Research entist, U.S. Department of Agriculture, Forest vice, Delaware, Ohio.

Behavior of Airborne Fluorides in Soils[1]

Janina Polomski, Hannes Flühler, and Peter Blaser[2]

Accumulation of airborne fluorides in soils is said to be a side effect of minor importance if it is compared with the phytotoxicity of man-made gaseous fluoride. When soil fluoride was considered in the past, F-uptake of plants, leaf injury or yield reduction was of prime concern. Not much is known about the fate of F-pollutants after being deposited onto the soil surface or incorporated in the plant litter layer. Our study aims at providing experimental tools and data for a better understanding of long-termed effects. The objective is to pin down the most significant, controlling mechanisms of the F-mobility in soils.

Field experiments: In the vicinity of a 30000 t Aluminum smelter, built 1908, we observed that F actually accumulates in the soil (Table). The soils sampled at various distances differ in many respect but are all calcareous. The F-contents do depend upon distance from the emission source.

distance from Al-smelter (km)	total F	watersoluble F	dissolved F (μg F per ml soil solution)	F-content of 1½-year old pine needles (ppm)
	(μg F per gram soil)			
0.5	2360	159	8.2	472
0.8	1760	153	—	443
1.0	1500	46	—	242
1.8	696	26	3.1	126
5.0	640	24	—	108
6.0	860	14	5.1	60
10.0	520	13	0.3	15

In soils, fluoride coexists in many different forms which makes the total F-content to be a hardly interpretable soil characteristics.

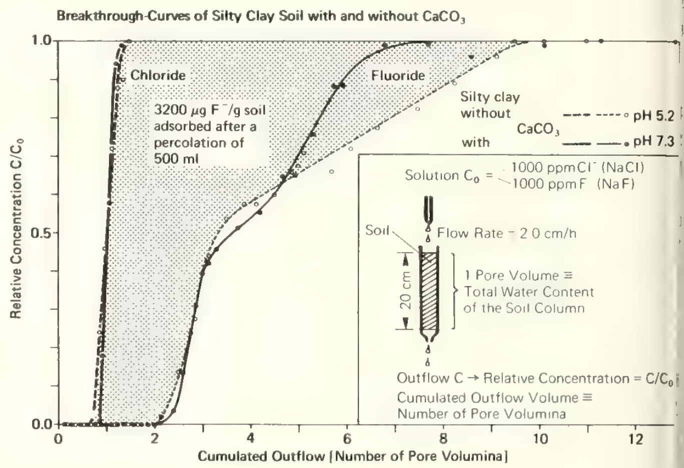
In a pine stand, located 1.8 km from the smelter the magnitude of the annual F-input and leaching losses were determined (kg F per y and ha) : 1-3 kg within dead plant material, 6-10 kg atmospheric washout, 40-80 kg adsorption and sedimentation. The leaching losses out of the root zone were estimated to be some 80-100 kg.

Under pine canopies the F-contents in the surface layer (humus) are systematically higher than in the subsoil (mineral horizon) whereas in uncultivated open land under grass cover fluoride accumulates in the subsoil.

[1]Presented at the Symposium on Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, June 22-27, 1980, Riverside, California, U.S.A.

[2]Agronomist, soil physicist and chemist, respectively, Swiss Forestry Research Institute, Birmensdorf, Switzerland.

Laboratory experiments: What controls the fluoride transport in soils? In case of a non-calcareous soil (pH 5.2) the amount of fluoride adsorbed within a mixture of soil and NaF-solution being equilibrated on a shaker (3340 μg F^-/g) soil equals approximately the F-adsorption in the course of a percolation through a soil slab (Fig.)



The close agreement between the two experiments indicates that adsorption and precipitation are fast reactions as compared with the velocity of the percolating soil solution. In calcareous soils, however, the exchange kinetics between the liquid and solid phase controls the extent of accumulation and depletion. The exchange proceeds too slow to keep up with the pace of the moving water. This explains the amazingly high F-mobility observed in case of the F-contaminated calcareous soils.

In the course of the percolation experiments the leachates from the soil columns contain appreciable amounts of solubilized organic matter and aluminum. For a given soil type the leaching losses depend in the first place upon the F-content of the infiltrating solution and further upon soil type and the F-compounds used to make up the percolating solution. Under field conditions with 8-10 ppm F in the soil solution such phenomena may also occur. A significant amount of soluble organic material can be lost which may represent an energy substrate shortage for the microorganisms, and furthermore the Al-concentrations possibly reach phytotoxic levels. At this point the experimental evidence rather backs up questions than provides definite answers.

Multiple Pollutant Fumigations Under Near Ambient Environmental Conditions Using a Linear Gradient Technique[1]

P.B. Reich, R.G. Amundson, and J.P. Lassoie[2]

Investigations of the impact of atmospheric ɔllutants on plants normally involve artificial-y raising the concentration of certain gases a-ɔund study plants. Such experiments typically tilize enclosures which greatly modify other nvironmental factors. Hence, these experiments ay not accurately test plant responses under mbient conditions. The development of open-top, ield fumigation chambers (Mandl and others 1973) nd a new linear gradient exposure system (Shinn nd others 1977) have been attempts to solve his problem.

In 1979 we constructed a modified linear gra-ient system and 6 open-top chambers. The gra-ient system enabled the simultaneous exposure of ımerous study plants to a concentration gradient f SO_2 and O_3. Since the system does not use nclosures, plants are easily accessed and ex-erience near-ambient environmental conditions. plot of soybeans (Glycine max. var. Hark) in thaca, NY was used in an attempt to answer the ollowing questions.

1) Can the gradient system be used to expose lants in the field to controlled levels of air ollutants without significantly altering their nvironments?

2) Is plant growth significantly different n open-top chambers versus in a linear gradient ystem?

3) What reductions in soybean seed yield will esult from exposure to moderate levels of SO_2 nd O_3 during the seed maturation period?

During the seed maturation period, the plants ere exposed to SO_2 and O_3 for about 55 h over a)-day period. On all occasions, a linear con-entration gradient was created by the system. ean concentrations of SO_2 and O_3 at the "high" nd of the gradient were 0.16 and 0.06 ppm, re-spectively, while ambient concentrations of both ollutants were about 0.02 ppm. Maximum hourly eans at the "high" end of the gradient were 0.50 nd 0.17 ppm SO_2 and O_3, respectively. By moni-oring the plot in a grid design, we were able) account for the effects of wind on pollutant evels. In the open-top chambers, plants were exposed to 0.30, 0.10, and 0.02 (ambient) ppm SO_2 for 72 h, over a 30-day period, during the pod-filling stage.

Comparisons of treatments revealed that the gradient fumigations reduced total bean yield per plant and dry mass per bean by as much as 39 and 14 percent, respectively. In the open-top chambers, total bean yield per plant and dry mass per bean were reduced by as much as 10 and 7 percent, respectively. It is of interest to note that both the "high" and "medium" (mean SO_2-0.09 ppm, mean O_3-0.04 ppm) treatments in the gradient system caused much greater reductions in yield than did the 0.30 ppm SO_2 treatment in the open-top chamber. In interpreting these data, one must remember that the plants in the gradient system did experience short-term peaks much higher than their mean concentration exposures.

In any case, O_3, although present at moderately low levels, was (alone or synergistically with SO_2) probably responsible for the greatest reductions in seed size and yield.

In open-top chambers, one can accurately control pollutant levels. In contrast, the linear gradient system allows fumigations which vary with time and wind, as under ambient conditions. The linear gradient system proved to be an effective means of fumigating plants with multiple pollutants under ambient environmental conditions. Another modification of the gradient system is currently underway so as to allow for analysis of the interactions between SO_2 and O_3, and the effects of such on various hardwood tree seedlings.

ACKNOWLEGMENTS

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[1]Presented at the Symposium on Effects of Air ɔllutants on Mediterranean and Temperate Forest cosystems, June 22-27, 1980, Riverside, alifornia, U.S.A.

[2]Graduate student of Forest Science, Cornell niversity, Ithaca, NY; Post Doctoral Associate, oyce Thompson Institute, Ithaca, NY; and Assis-ant Professor of Forest Science, Cornell niversity, Ithaca, NY.

Changes in Plant Communities with Distance from an SO_2 Source[1]

Paul R. Scale[2]

Investigations were carried out to assess the effects on plant community composition of sulphur dioxide (SO_2) emitted from an iron sintering plant in Wawa, Ontario, Canada. Diversity indices and the ordination techniques of Correspondence Analysis (C.A.) and Principal Component Analysis (P.C.A.) were used to discern community level changes. Of special interest were the subtle changes in areas noted to be only slightly affected by SO_2 emissions. Over 60 upland birch stands were accessed along a north-easterly transect away from the source at distances of 12 to 55 km. Species specific data was collected on the tree, shrub and ground flora.

Changes in species composition are dramatic as the 30 year SO_2 source is approached. The total percent cover of the dominant, predominantly boreal, ground flora species are shown in Figure 1. They reflect the complex pattern of species abundance which occurs along the transect. Characteristic is the transitory increase in abundance which occurs in most species. What is particularly evident is the ability of many species to take advantage of the increasing damage caused first to the tree canopy and subsequently to the shrub layer. This occurs despite their own greater exposure to SO_2. The low-bush blueberry (Vaccinium angustifolium Ait.) for example, becomes very abundant at distances of 20 to 30 km yet shows considerable SO_2 damage in that area. The first substantial change in species abundance occurs at a distance of 40 km where beaked hazel (Corylus cornuta Marsh.) becomes very abundant before a very rapid decline. This undoubtedly contributes to the drop in the abundance of the large leaved aster (Aster macrophyllus L.) at that distance.

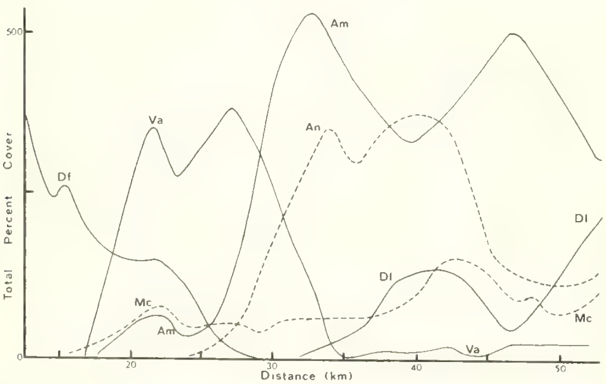

Figure 1--Changes in ground flora species abundance with distance using a running average of percent cover: Am, Aster macrophyllus; An, Aralia nudicaulis; Df, Deschampsia flexuosa; Dl, Diervilla lonicera; Mc, Maianthemum canadense; Va, Vaccinium angustifolium.

Dealing collectively with all species of a community to discern changes caused by a pollutant is, for theoretical reasons and from experience, a more satisfactory approach than changes in individual species abundance. Diversity indices have been used extensively for this purpose. However, the data from Wawa indicates that although diversity indices can deal with spatial/structural changes in the community, they do not adequately reflect the subtler changes in species composition. Ordination techniques, such as C.A. and P.C.A., are better suited for this purpose. For example, the Shannon-Weiner Diversity index has a transitory increase between 20 and 30 km before declining at distances below 20 km. In contrast, the first axis of C.A. using ground flora data shows a simple linear change from 12 to 33 km (Figure 2). C.A. is most effective in reflecting overall trends whereas P.C.A. is particularly useful in discerning differences in stands of very similar composition. On the basis of P.C.A. using shrub density data, the separation of sites in intermediate areas from controls can be achieved. The boundary between the two groups in Figure 2 corresponds well with the line designated in 1973 and 1974 as separating areas which do and do not show visible leaf damage.

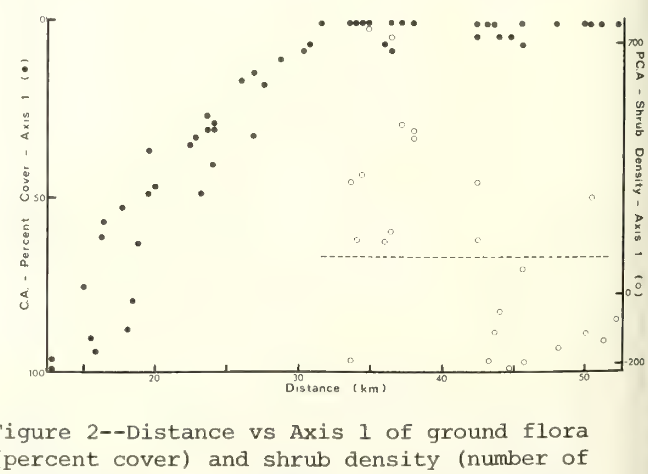

Figure 2--Distance vs Axis 1 of ground flora (percent cover) and shrub density (number of stems under 5 cm diameter at breast height) data using C.A. and P.C.A., respectively.

[1] Presented at the Symposium on Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, June 22-27, 1980, Riverside, California, U.S.A.

[2] Graduate Student, Institute for Environmental Studies, University of Toronto, Toronto, Ontario, Canada.

Lichens as Ecological Indicators of Photochemical Oxidant Air Pollution[1]

Lorene L. Sigal and Thomas H. Nash III[2]

From the late 1960's to the present, both the concentration and dose of photochemical oxidant air pollutants (ozone and peroxyacetyl nitrate or PAN) have continued to increase in the mountainous areas surrounding the Los Angeles Basin. Since 1972, a multi-disciplinary team of ecologists has monitored and analyzed the ecological consequences of this pollution in the conifer forest ecosystem of the San Bernardino Mountains. Our lichen study parallels and expands the parameters of the aforementioned study and allows a comparison of the relative sensitivity of lichens versus higher plants to oxidants.

Historically, lichens have been demonstrated to be sensitive indicators of air pollutants such as sulfur dioxide. More recently, there is strong evidence that lichens are also sensitive to hydrogen fluoride and heavy metals. The present study documents for the first time that lichens are also sensitive to ozone and peroxyacetyl nitrate.

Field investigations were conducted in four mountain ranges surrounding the Los Angeles Basin. A fifth site in Cuyamaca Rancho State Park, east of San Diego, was chosen as the control area. Results of sampling lichens on *Quercus kelloggii* Newb. and conifers showed overall species richness decreased by 38 percent in the highly impacted San Bernardino Mountains. Cover values for species on *Q. kelloggii* decreased by 16 percent; for lichens on conifers the decrease was 78 percent. The latter decrease is large due to the fact that the "sensitive" fruticose lichen species are found mainly on conifers. There was an inverse relationship between the cover of lichens at breast height on conifers and the oxidant dose estimates at sites in the San Bernardino Mountains (fig. 1). A threshold is seen at 180 ppm-hrs above which the lichens are almost absent.

Fumigation studies in the laboratory provided a definitive way of testing the response of field sensitive and field tolerant species to controlled concentrations of ozone and PAN similar to those occurring in the field. Injury was documented as a significant reduction in gross photosynthesis. *Parmelia sulcata* Tayl. exhibited greater sensitivity to ozone and PAN than *Hypogymnia enteromorpha* (Ach.) Nyl. These results were consistent with field observations.

As a result of collections made by H. E. Hasse and the subsequent publication of his "Lichen Flora of Southern California" in 1913, the present distribution and vitality of a number of lichens was compared to their distribution at the turn of the century. There was a 50 percent decrease in species richness. In addition, marked morphological deterioration was seen in the thalli of existing folose species such as *Hypogymnia enteromorpha*. Forty-two percent of the thalli collected in the San Bernardinos were bleached and 44 percent were convoluted in contrast to no bleaching or convolution in collections made in the Cuymacas. Thallus dimensions were decreased by approximately 50 percent in the San Bernardino collections.

The importance of lichen studies lies in their sensitivity to air pollution and their potential use as bioindicators. By monitoring the abundance and distribution of sensitive lichens, it is possible to estimate the magnitude of air pollution. Use of lichens in this matter may be feasible not only as currently applied in northern Europe with sulfur dioxide air pollution, but also over large geographical areas impacted by photochemical oxidant air pollution.

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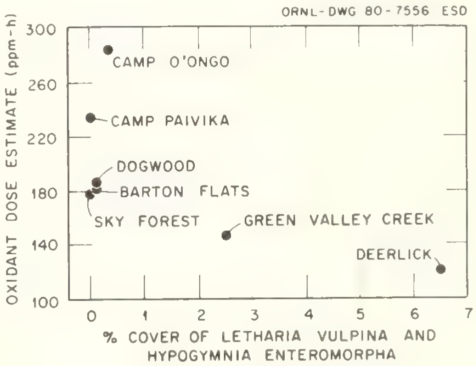

Figure 1--Percent linear cover at breast height of *Letharia vulpina* (L.) Hue and *Hypogymnia enteromorpha* (Ach.) Nyl. as a function of the oxidant dose estimates (ppm - hrs. = the mean oxidant concentration in ppm multiplied by the time of exposure) at sites in the San Bernardino Mountains.

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[1] Presented at the Symposium on Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, June 22-27, 1980, Riverside, California, U.S.A.

[2] Research Associate, Oak Ridge National Laboratory, Environmental Sciences Division, P.O. Box X, Oak Ridge, Tenn. 37830. Operated by Union Carbide Corporation under contract W-7405-eng-26 with the U.S. Department of Energy; and Associate Professor of Ecology and Lichenology, Arizona State University, Tempe, Ariz. 85281.

The Effects of Air Pollutants on Forest Ecosystems in S.R. Slovenia[1]

Marjan Šolar

INTRODUCTORY DATA

Slovenia with its surface of 20,251 km^2 represents 8% of the territory of Yugoslavia (255,804 km^2). It is situated in the extreme northwestern part of the state between the Alps, the Pannonian plain, the Adriatic sea and the Dinaric orographic system. Half of the surface is covered by forests (1,000,000 ha), 2/3 of which are privately owned. The portion of conifers amounts to 56%, the average wood mass is nearly 200 m^3/ ha. The total increment per year is 4,000,000 m^3, the cutting 3,000,000 m^3. Two-thirds of the wood harvest possess a technical value. The portion of forestry within the national income is 4% and indicates well the level of the industrial development of Slovenia.

Slovenia is divided up into 15 forest management areas and each of those into the socially and privately owned sectors. The principles of management are unified. The basic principle is to manage as much pronaturally as possible to secure the permanency of yield and functions of the forest. The forest service enjoys in some places a 200-year tradition.

The study of effects of air pollutants on the forests goes back to the year 1926, and systematic investigations were started in 1969.

OBJECTIVES OF INVESTIGATION

We wish to determine the parameters, intensity and perspectives of the effects of air pollution on the forests in Slovenia, with the aim to secure reliable foundations for the planning of the industrial development running parallelly with the preservation of the multifunctional forest, for the regulation of indemnities and the elaboration of correct normative concerning the maximum tolerable concentrations valuable for this specific forest area.

PRELIMINARY FOUNDATIONS REQUIRED

Ecology (geology, soils, phytocoenology, climate) as bases for the determination of forest ecosystems not stressed by emission, forest inventory as a basis for the determination of the normal management situation of the forests and a register of emitters.

METHODS OF ASSESSING THE EFFECTS OF POLLUTED AIR ON FORESTS

Symptomatics, chemical analyses, increment analyses, bioindicators, presence of differently aged needles, presence of secondary pests, infracolor-aerophotographs.

SPECIFIC FEATURES OF THE TERRITORY OF SLOVENIA

Accentuated configuration, industry often located in narrow valleys, temperature inversion, extremely high emission values (shocks), high proportion of susceptible conifers, erodible soils, predominancy of SO_2 and HF.

RESULTS OF INVESTIGATION

The total surface of visibly damaged forests in S.R. Slovenia amounts to 22,000 ha i.e. 2.2% of the total forest area (situation in 1977). The internal division of damaged forests is the following:
Group A-the narrower emission area- the forest destroyed and existensially threatened, or surfaces under the impact of critical emission conditions entailing the total destruction of all forest functions-destruction of the forest ecosystem. Surface 4,000 ha.
Group B-the wider emission area-forest under permanent emission impact, yet the existence of the forest is not threatened, its functions are however reduced, or surfaces under to heavy emission conditions to allow a normal thriving of the forest. The emission causes an instability of forest ecosystems. Surface 16,000 ha.
Group C-Periodic emission area-periodic occurrence f damages, possibly acute ones, but between individual emission influences in every case longer norma situations are intercalated during which the forest can recover. Surface 2,000 ha.

Based on the chemical analyses of Spruce needle as to the increased content of sulphur and fluorid the surface of forests with hidden injuries is estimated to 25,000 ha. Survey and detailed maps of injured forest have been made for all bigger emissions areas. On the basis of relative resistance capacity of forest trees and of their proportional presence in the forest vegetation communities a categorization of forests with respect to their susceptibility to air pollution has been carried o.

The process of a further improvement of the emission damages in the forests observed during th last three years is not likely to proceed because of the increase of consumption of coal possessing high contents of combustible sulphur.

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[1]Presented at the Symposium on Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, June 22-27, 1980, Riverside, California, U.S.A.

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CONCLUSIONS

On the basis of investigations carried out in he total forest area of Slovenia influenced by mission, of knowledge concerning the ecology of his territory and the particularities of effects f the polluted air, we are able to predict exact-y the future of a certain forest under certain mission influence.

The standpoint of foresters is always the fol-owing: Wherever the forest has been destroyed r is on the way of destruction, the air is lo-ally polluted to a relatively critical extent. he air pollution is too high also in places here the forest is hampered in its development. ppealing to the normatives fixed by law and oncerning the maximum emission values allowed means nothing but that the normatives are set too high and that the foresters are bound to lower them.

The Resolution issued on the X^{th} Meeting of the IUFRO Group 2.09-Air Pollution, Ljubljana 1978 is proposing the normatives insuring the normal thriving of all kind of forests on average and extreme sites. The values for SO_2 are following (in $\mu g/m^3$/air): 50 as yearly average, 100 as 24 h average, 150 as $\frac{1}{2}$ h value, and for HF (in $\mu g/m^3$/air) 0.3 as yearly average and 0.9 as $\frac{1}{2}$ h value. For extreme sites the normatives are twice as sharp.

If we compare the normatives fixed by Resolution to those fixed by law in different countries we realise the last ones are much too high.

Population Differences in Response to Sulfur Dioxide: a Physiological Analysis[1]

G. E. Taylor, Jr. and D. T. Tingey[2]

The environment exerts a profound influence on a plant's ability to survive and reproduce, and consequently vegetation in a given area will possess a set of morphological and physiological traits that enhance fitness. At the level of populations, these site-specific attributes arise through either a modification of the phenotype (phenotypic plasticity) or a change in the gene pool (ecogenetic adaptation). Both responses are common strategies among natural populations experiencing disparate climatic, edaphic and biotic stresses. It is hypothesized that elevated levels of atmospheric pollutants have elicited in a comparable manner a variety of traits that enhance survival and reproduction in native plants inhabiting pollution-stressed areas.

One example of ecogenetic adaptation in response to air pollution is the evolution of sulfur dioxide resistance within populations of Geranium carolinianum, an herbaceous winter annual common in disturbed habitats in the Southeastern United States. In comparison with their counterparts from pollution-free regions, populations sampled from areas experiencing variable SO_2 stress for 31 years were consistently more resistant to SO_2 under controlled exposure conditions. This infraspecific variation is genetically determined and quantitatively controlled. Plants of contrasting SO_2 resistance were used to investigate the physiological basis of this adaptation. Individual plants were placed in a whole-plant gaseous exchange system in which concurrent steady state measures of leaf resistance to water vapor efflux and SO_2 influx were monitored in the dark and light at pollutant concentrations of 0.4, 0.6, and 0.8 ul l^{-1}. For resistant and sensitive plants at each concentration, estimates of total SO_2 flux ($\mu g\ cm^{-2} hr^{-1}$) as a function of leaf resistance to H_2O efflux were modeled using linear regression techniques. From estimation procedures, total flux was partitioned into leaf surface and internal fractions.

Total SO_2 flux varied as a function of leaf resistance and did not differ among resistant and sensitive plants at 0.4 and 0.6 ul l^{-1} SO_2. Conversely, at the highest concentration total SO_2 flux was not the same for the 2 plant groups as a consequence of disparate slope parameters. Irrespective of concentration the leaf surface and interior were major sinks for SO_2 (Fig. 1). Each fraction increased linearly with concentration, however the ratio of internal to total flux decreased steadily. The absolute values for internal SO_2 flux were strikingly similar for both plant groups at each concentration. Therefore, in spite of the variation in total SO_2 flux to the plant, the rate of SO_2 absorbed into the leaf interior was equivalent for resistant and sensitive plants. Since leaf resistance to water vapor efflux is the same for all plants in both ambient and SO_2-polluted atmospheres, overt plant-to-plant differences in their response to SO_2 reflect disparate internal biochemical processes affecting pollutant toxicity, perturbation or cellular repair.

The fact that plant differences in response to SO_2 are genetically controlled and not a result of pollutant exclusion is relevant to an understanding of the rapid evolution of population resistance in G. carolinianum. This species is an annual that thrives for six months as a winter rosette during which new leaf growth is minimal and yet transpiration remains active. This habit coupled with the plant's inability to track and exclude elevated levels of SO_2 may predispose this species to accumulate more SO_2 derivatives than other co-occurring species that are either more ephemeral or capable of avoiding SO_2 uptake via increasing stomatal resistance. These species' attributes may explain the consistent field observations that show G. carolinianum to be a sensitive biological indicator of elevated SO_2 levels.

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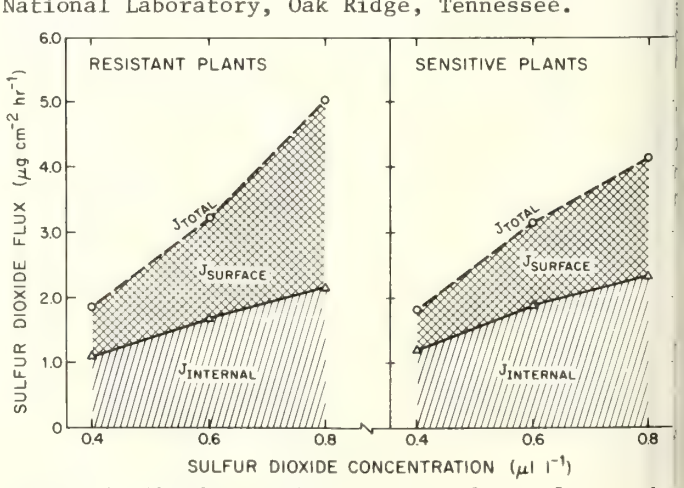

Figure 1--Absolute values for total, surface and internal leaf flux of SO_2 as a function of pollutant concentration in resistant and sensitive plants.

[1]Presented at the Symposium on Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, June 22-27, 1980, Riverside, California, U.S.A.

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Ozone Injury to Pines in the Southern Sierra Nevada of California[1]

Detlev R. Vogler and John Pronos[2]

The Forest Service began evaluating the impact f ozone on Sierra Nevada forests in 1974. Evalation efforts were expanded and intensified in 977, and since then the primary methods of ssessment have included, (1) monitoring ambient zone levels, and (2) rating injury to pine folage in permanent trend plots.

Air pollution injury to commercial pine stands ocated between 4000 and 8000 feet elevation ccurs quite uniformly along most of the southern ierra Nevada front range adjacent to the San oaquin Valley and up into the major river drainges. Symptoms are not confined to localized reas downwind from major pollutant sources. ather, ozone is carried down the entire San oaquin Air Basin and eastward into the Sierra. etropolitan areas contributing to the ozone dose nclude Stockton, Modesto, Merced, Fresno, isalia, Bakersfield, and perhaps even Sacramento nd the San Francisco Bay Area.

OZONE MONITORING

Five forested locations in the southern Sierra ere monitored for season-long ozone dosages etween 1977 and 1979. One site -- Whitaker orest -- was monitored continuously during this -year period. The sites ranged in elevation rom 5400 feet to 7540 feet, and all were at east 50 miles from suspected metropolitan sources f air pollution.

Ozone levels at each site exceeded both the ederal (0.12 ppm) and State (0.10 ppm) Standards ach year they were recorded. Based on the numer of hours exceeding the Standards, 1977 was he worst year for ozone, while levels declined teadily in 1978 and 1979. During the summer of ach year daily peak ozone values commonly ranged etween 0.10 ppm and 0.14 ppm. These values can e compared to those in the San Bernardino Mounains of southern California, where maximum daily zone levels frequently range from 0.20 to 0.33 pm, and where injury to pine forests is corresondingly more severe.

TREND PLOTS

Trend plot data were collected for three consecutive years beginning in 1977. In 1977 and 1978 ozone injury ratings of plots scattered throughout a sampling area of over 1 million acres ranged between no injury and moderate injury. Although the majority of 1978 plots showed more oxidant symptoms than 1977 plots, there was no statistically significant trend evident. The change between 1977 and 1979, however, was more dramatic. Nineteen of 27 plots evaluated in 1979 showed additional injury over 1977 levels, and seven of these plot differences were statistically significant ($P = 0.05$). In 1979, for the first time, several plots fell into the severe injury category. The trees in these plots averaged 2 years of needle retention with ozone symptoms on 2-year-old needles.

This obvious increase in injury was not expected because measured ozone levels in 1979 were generally lower than in either 1978 or 1977. Considerable physiological stress from a 2-year drought (1976-1977) could account for part of the observed increase in foliar injury. One visible response of pines to the drought was a dramatic decrease in needle retention, which tended to produce more severe ozone injury ratings. Future recovery of trees from drought stress, in the form of increased needle retention, may result in a relative reduction of measureable air pollution injury during the next few years.

CONCLUSIONS

The overall level of forest-wide injury in the southern Sierra Nevada can be termed slight, with some local populations of susceptible pines showing moderate or worse injury. Unexpectedly high amounts of injury detected in certain areas in 1979 placed some plots into the severe category. It is presently unclear whether this is a permanent trend of increasing impact, or just a short-term result of drought stress.

With only 3 years of monitoring data, trends in annual ozone dose are difficult to assess. Ozone levels seemed to decrease slightly each year between 1977 and 1979, even though visible injury to pines increased. Measured variations in seasonal ozone dose may be associated more with weather patterns than with decreased pollutants at the source. Maximum daily ozone values in the Sierra still remain about 1/2 or less of those occurring in southern California. As ozone continues to be transported into the western slopes of the Sierra Nevada, sensitive pines will continue to show additional injury and will slowly decline.

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[1]Presented at the Symposium on Effects of Air ollutants on Mediterranean and Temperate Forest cosystems, June 22-27, 1980, Riverside, alifornia, U.S.A.

[2]Plant Pathologists, Pacific Southwest Region, orest Service, U.S. Department of Agriculture, an Francisco, California.

Modifications of Chemical Contents of Precipitation by Passage through Oak Forests[1]

George T. Weaver and Jon D. Jones[2]

Bulk precipitation monitored within oak forests in the Ozark Physiographic Province in Illinois was strongly acidic (pH<4.5) throughout most of 1978. Exceptions occurred during late summer and early autumn when pH rose to 5.8. This pattern with similar pH values reoccurred during the autumn and winter of 1979-80 and differs from seasonal trends usually reported from the northeastern United States where periods of greatest and least acidity are summer and winter, respectively. During the 1979-80 period, the highest concentrations of SO_4^{2-} occurred during autumn, and on an equivalence basis, exceeded H^+ concentrations by a factor of 10. Concentrations of Ca^{2+}, Mg^{2+}, and K^+ were also high during autumn. It is hypothesized that considerable neutralization of strong acids occurred in the atmosphere due to the presence of airborne dust which normally exists during autumn.

Additional neutralization occurred as precipitation passed through the forest canopy, especially during autumnal leaf senescence. At this time canopy drip pH exceeded bulk precipitation pH by up to 0.7 units. The concentrations of Ca^{2+}, Mg^{2+}, K^+, SO_4^{2-} and PO_4^{3-} in canopy drip increased markedly compared to bulk precipitation, particularly during autumn. During the winter, canopy drip pH decreased to values as low as 3.8 and differed little from bulk precipitation pH. In 1978, 68 percent of the precipitation reaching the forest floor as canopy drip was acidic (pH<5.6). The removal of nutrient ions from the canopy also decreased during winter. In the spring of 1980 maximum bulk precipitation pH was 6.6 but passage through the canopy caused a decrease in pH as great as 0.8 units. Soluble organic compounds, apparently leached from some oaks, were present in sufficient quantities to impart a dark stain to canopy drip during this period and may be associated with the reversal in H^+ exchange in the canopy.

The concentrations of ions in soil water formed three distinct patterns relative to concentrations in bulk precipitation and canopy drip. Hydrogen ion concentration was decreased markedly by passage through these ecosystems and the quantity remaining in soil water was only about 10 percent as great as in bulk precipitation. The concentrations of four ions - SO_4^{2-}, NO_3^-, Ca^{2+}. and Mg^{2+} - increased as water passed through these ecosystems. The levels of these ions in soil water were as great as 37 times and 9 times the levels in bulk precipitation and canopy drip, respectively, although major differences occurred among seasons and between ions. The contents of K^+ and PO_4^{3-} in bulk precipitation also were increased by up to 25 times by passage through the forest canopy. However, concentrations of these particular ions either decreased or remained similar to concentrations in canopy drip after passage through the soil.

Between October 1979 and April 1980, Ca^{2+} and SO_4^{2-} were the predominant ions (equivalence basis associated with meteorologic and hydrologic processes in these ecosystems. The importance of Ca^{2+} in these ecosystems was anticipated since it is selectively accumulated by some species of oaks in these forests. It is also apparent that elevated levels of H^+ are being deposited in association with SO_4^{2-} in these ecosystems, but the impacts remain undetermined.

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[1]Presented at the Symposium on Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, June 22-27, 1980, Riverside, California, U.S.A.

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Seasonal Variation of Inorganic and Organic Sulfur in Coniferous Needles Intensified by SO_2 Pollution[1]

Karl Friedrich Wentzel und Günther Gasch[2]

Method:

Needles from 50 - 70 year old Norway spruce from 1. gardens and parks of Wiesbaden town (slight damage), and 2. Wiesbaden forests (no visible injury) were used as bioindicators for SO_2-uptake. In octobre we picked 0.5, 1.5 and 2.5 year old needles, in may we picked 1, 2 and 3 year old needles from the tops of the same trees. Inorganic and organic sulfur was determined according to Jäger und Steubing (1970).

Results:

1. Air pollution measurement 1976 - 1979. Datas in microgramm SO_2 per cbm air. I1 = annual average, I2 = 95 percentile of 30 min. values:

Zone	I 1	I 2
Industrial Area	120 - 140	400 - 500
Town	70 - 90	200 - 300
Forests	< 50	< 120

2. Total sulfur content increases with needle age as shown in Fig. 2. In town the S contents of the needles are 100 - 200 ppm higher than those from the forests.

3. The inorganic fraction of all needle samples surmounts the organic fraction. The difference is greater in autumn than in spring and more apparent in town than in the forests.

4. The validity of using coniferous needles as indicator of air pollution effects is best when octobre datas of inorganic S are used.

5. Organic sulfur content decreases during the vegetation period while the inorganic fraction increases. During winter time the opposite occurs (Fig. 3). From this it is suggested that in spring time a part of the organic sulfur demand is covered by removing the inorganic amount, which partially is of air-borne origin.

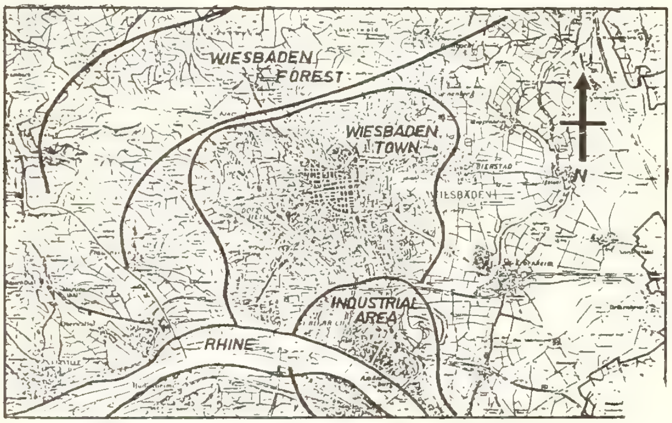

Fig. 1 : Map of Wiesbaden/FRG

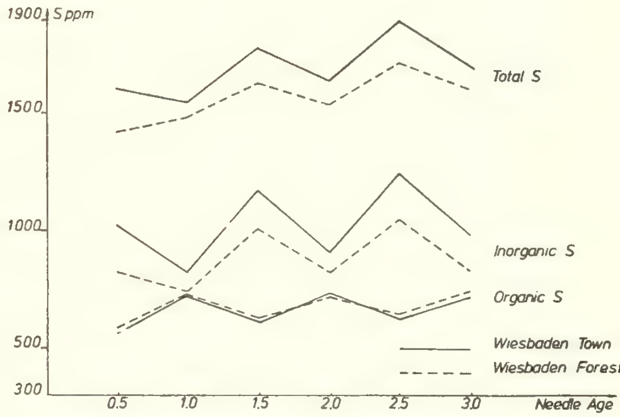

Fig. 2 : Sulfur content (ppm of dr. wt.) in spruce needles from Wiesbaden town (means of 39 tree samples) and forests (means of 16 tree samples).

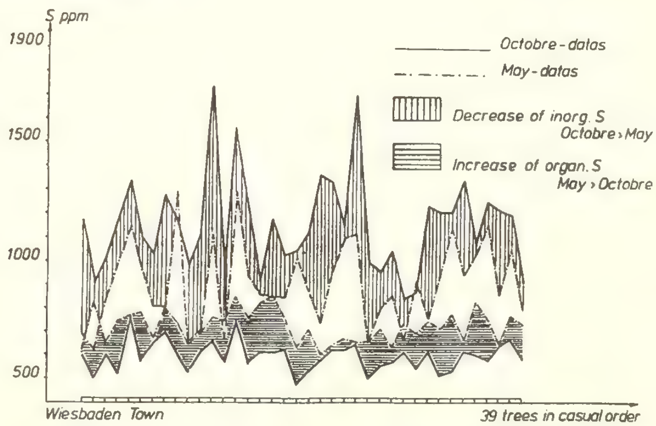

Fig. 3 : Seasonal alteration of inorganic and organic S in spruce needles from Wiesbaden town (means of 6 semi-annual needle sets).

1 Presented at the International Symposium on Effects of Air Pollutants on Mediterranean and Temperate Forese Ecosystems, June 22-27, 1980, Riverside, California, U.S.A.

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Sulfur Dioxide and Oxidant Effects on Californian Coastal Sage Scrub[1]

W.E. Westman and K.P. Preston[2]

Two field studies have related oxidant and sulfur dioxide pollution to a deterioration in the structure and function of southern California's drought-deciduous shrublands (coastal sage scrub). In a study of 67 sites (0.63ha) from San Francisco to El Rosario (Baja California), data were collected on species cover and 43 habitat variables describing topography, soil, climate, vegetation structure, age since fire, grazing intensity, and air pollution of sites. The variable which showed the highest significant correlation with percent foliar cover of native species was the mean annual oxidant concentration ($r=-.58$, $P<.001$). Elevation and mean maximum temperature of the warmest month also showed highly significant correlations ($r=-.52$). The partial correlation coefficients of oxidants with percent cover remained high when covariations with elevation, mean maximum temperature of the warmest month,and distance from the coast were extracted ($r=-.41,-.35,-.42$ respectively). The interrelationships of these variables were investigated further by means of path analysis. A path model (chi-square probability = .87) related environmental factors to a reduction in the percent cover of native species. The path model suggested that other factors correlated with declining cover were acting primarily through their influence on oxidant concentration in predicting the decline in cover of native scrub species.

Increasing concentrations of oxidants were also associated with a decline in species richness ($r=-.23$; $P<.05$) and increase in equitability (Whittaker's E_c index; $r=.24$; $P<.05$). Diversity in floristically similar sites of high and low annual oxidant concentrations was compared. Highly polluted sites have fewer species per abundance class and a lower total species richness ($\overline{X}=18$ v. $\overline{X}=29$ at less polluted sites). Concentration of dominance increases in the more polluted sites. Major results have been reported in Westman (1979).

In a second field study, the effects of sulfur dioxide emissions (up to 0.13 ppm for a period of 25 years) from an oil refinery were studied near Santa Maria, on the rural central coast of California. Stands of coastal sage scrub with black sage (Salvia mellifera) downwind of the refinery were compared with stands in relatively pollution-free upwind sites. Injury to individual Salvia shrubs and changes in community structure and floristic composition were recorded. Stomatal resistance was found to be significantly lower on the polluted sites with a concomitant 35 percent increase in mean transpiration rates of Salvia. Flowering capacity of Salvia, measured by the number of flower whorls per flower spike, was also significantly reduced. Significant decreases in the height/width ratio of Salvia were hypothesized to be caused by sulfite-mediated destruction of indole acetic acid (Yang and Saleh, 1973) and possible inhibition of apical dominance. Significant reductions in photosynthetically active tissue of Salvia resulted from increased defoliation and reduction in leaf size associated with SO_2 stress. The evidence indicates that these factors decreased the shrubs' ability to compete with the more r-selected annuals. As such, the number of species, primarily annuals, increased considerably in the most polluted sites ($\overline{X}=27$ v. $\overline{X}=18$ on control sites). These SO_2 -associated changes in community structure and floristic composition suggest that retrogression is occurring, causing the 26-year old stand to resemble a 7-year old post-fire seral stage. Results are reported more fully in Preston (1980). Laboratory studies are in progress to assess sensitivity of sage scrub species to SO_2 injury.

[1]Presented at the Symposium on Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, June 22-27, 1980, Riverside, California, U.S.A.

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These proceedings papers and poster summaries discuss the influence of air pollution on terrestrial and related aquatic ecosystems. They describe single species-single pollutant relationships; interactions of producers, consumers, and decomposers under pollutant stress; and the use of ecological systems models for interpreting and predicting pollutant effects.

Retrieval Terms: air pollution injury, acidic precipitation, pollutant stress, terrestrial habitats, species-pollutant relationship, mathematical models.